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NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF CIVIL ENGINEERING
DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

AGENT BASED MODELLING OF DOMESTIC WATER DEMAND FOR ADAPTIVE URBAN WATER MANAGEMENT

DOCTORAL THESIS

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ATHENS, 2015

European Union
European Social Fund
OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS
MANAGING AUTHORITY
Co-financed by Greece and the European Union
NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND

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ΑΘΗΝΑ, 2015

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
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ΕΣΠΑ 2007-2013
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Η παρούσα έρευνα έχει συγχρηματοδοτηθεί από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο - ΕΚΤ) και από εθνικούς πόρους μέσω του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» του Εθνικού Στρατηγικού Πλαισίου Αναφοράς (ΕΣΠΑ) – Ερευνητικό Χρηματοδοτούμενο Έργο: Ηράκλειτος ΙΙ Επένδυση στην κοινωνία της γνώσης μέσω του Ευρωπαϊκού Κοινωνικού Ταμείου.”

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο

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ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

European Union
European Social Fund

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στον Χάρη και στην Καλλιστώ

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ABM	Agent Based Modelling
EYDAP S.A.	Athens Water Supply and Sewerage Company S.A.
ODD protocol	Object Design Description protocol
UML	Unified Modelling Language
UWAB	Urban Water Agent's Behaviour
UWOT	Urban Water Optioneering Tool

Acknowledgments

"Only in silence the word,
Only in dark the light,
Only in dying life:
Bright the hawk's flight
On the empty sky"
Ursula K. Le Guin

It is truly difficult to depict the transformations, personal and professional, one has to go through, while pursuing a PhD, so I can only acknowledge all those people, that have stood by me during this journey.

First and foremost, I would like to express my gratitude to Assistant Professor Christos Makropoulos for being a mentor of mine for several years starting as a co-supervisor in my M.Sc. Thesis at Imperial College London, in 2005, and continuing as my supervisor in my PhD research. A big thank you for trusting me with this research subject, for believing in me, for successfully translating my words into research objectives and results and for once telling me "either you do it or you don't" that forced me to get on with this research.

A big thank you to Professor Maria Mimikou for her part in the supervision of this PhD research and including me in her team of associate researchers in the Centre of Hydrology and Informatics as I was waiting for a PhD research funding. Additionally, I would like to thank Dr. Nick Voulvoulis of Imperial College London for supervising this PhD research and offering valuable advices.

This PhD research could not have been attempted without financial support through the Research Funding Program: Heracleitus II. I would like to thank Patty Karagkiozopoulou and Manolis Tsimas that made all the bureaucratic work easier and were always patient and available for answering all of my questions.

I would like to express my gratitude to all of my colleagues at the Laboratory of Hydrology and Water Resources Management that have created a lively working environment full of camaraderie, and in particular to: PhD candidate Chrysoula Papathanasiou who has offered many hours of her busy schedule for discussions of both scientific and personal nature; PhD candidate Sandra Baki who provided me with many practical solutions and invaluable advices both scientific and personal; Dr. Evangelos Rozos for all his advices in programming and for reviewing my papers and Dr. Patricia Gerakopoulou for introducing social psychology to me. Last but not least, a special thank you to my office-mates and colleagues for always making time to discuss with me my PhD worries: Patricia Gourgoura, George Karavokyros, Panagiotis Kossieris, Archontia Lykou and Giannis Tsoukalas.

I feel particularly aware of how much one depends upon the social network that is one’s friends and family, and I have been extremely lucky having around me people that were always willing to help me, when asked. From all those eager to be there for me, I would like to say a special thank you, to those that provided me with practical help, while I was pursuing this PhD. First of all, I would like to thank Dr. Kostantinos Eftaxias for helping me in my first slow and hesitant steps in programming. Additionally, I would like to thank my friends Asimina Georgakopoulou, Nadi Kapou, Evi Noula, and Lefki Sakellariou for editing texts and listening to me, even though they rarely understood what I was talking about.

Last but not least, I am deeply grateful to my parents Dora and Nikos that set the strongest foundations of unconditional love and complete support in any possible way throughout my life. All my dreams and pursues would never be complete without Chari by my side, to whom I owe a huge thank you for his patience and support every time I need to lift myself up and continue. Finally, I am deeply grateful to my little daughter Callisto for enduring in her first 21 months of life, a full time PhD student mom.

Executive Summary

1. Introduction

The urban water system is a complex adaptive system composed of technical, environmental and social components (water infrastructure, water resources and water users respectively) which interact dynamically and continuously with each other. The relationships between these components evolve in time, particularly in view of the dynamic and bottom up nature of water demand behaviours and patterns, thus increasing the uncertainty regarding responses to changes and interventions (House-Peters and Chang, 2011). More integrated, system-level approaches to the urban water cycle, attempting to manage both supply and demand, through an unified urban cycle management framework have recently been emerging in the literature (including for example Rozos and Makropoulos 2013; Behzadian et al., 2014; Back et al., 2014), but even these, leave the water end-user essentially out of the simulation domain.

Two of the main challenges in embedding the water end-user into the urban water cycle are (a) the estimation of the behaviour of households in terms of water demand and (b) the quantification of the way in which this behaviour is affected by water demand management measures such as awareness raising campaigns and water price changes.

In this work, the water demand behaviour of urban households is simulated using theoretical frameworks developed in the social psychology domain, aiming to provide a conceptual model of how human behaviour is influenced and shaped by others (Allport, 1954; Hogg and Vaugnan, 2011) and of the potential association between attitudes, intentions and actual behaviours (Ajzen, 1991).

The simulation environment that was selected to model the implications of social psychology theories on the behaviour of water users is Agent Based Modelling (ABM). ABM has the ability to capture emerging (bottom-up) behaviour, simulating the dynamic interaction between the socio-economic and the water system and hence to provide the missing link to modelling the complete socio-technical water system as one (Wheater et al., 2007, Koutiva and Makropoulos, 2011; Filatova et al. 2013). ABM uses intelligent agents defined as "computer systems situated in some environment, capable of autonomous action in this environment in order to meet its design objectives" (Wooldridge, 1999). Essentially, ABM is a form of computational social science (Gilbert, 2008) where agents are able to support *emergence*[1] thus creating complex behaviour from the interaction of simple components.

In this work an ABM was developed, which was named the "Urban Water Agents Behavioural Model" (UWAB), which simulates the urban household's water demand behaviour based on: (a) complex network theory (Albert and Barabasi, 2000) representing the links among the domestic water users of a city; (b) Social Impact Theory (Latane, 1981) addressing the effects of society, policies and other external forces on the domestic users' behaviour; (c) the Theory of Planned Behaviour (Ajzen, 1991) deconstructing the domestic water user's behaviour into components for modelling behavioural intention; and (d) statistical mechanics (Shell, 2014) employed to deal with the inherently stochastic nature of human behaviour.

Results on behavioural changes due to demand management policies and environmental pressures were simulated with the UWAB model and were then translated into specific domestic water demands through micro-simulation of in-house water appliances using the Urban Water Optioneering Tool (UWOT) (Makropoulos et al., 2008). The UWAB-UWOT modelling platform was then demonstrated using the Athens urban water system as an example. Initially, the UWAB-UWOT modelling platform was calibrated and validated using a major period of drought in Athens, Greece. The calibrated UWAB-UWOT modelling platform was then used to develop scenarios of future water demand by modelling the effects of different water demand management strategies on the water cycle of the city of Athens. The results suggested that the coupling of the two models provides a new way of planning and assessing water demand management strategies of direct relevance to water regulators and water companies.

2. The Urban Water Agent Behaviour (UWAB) model

The Urban Water Agent Behaviour (UWAB) model was created, using the NetLogo agent programming language (Wilensky, 1999), to simulate the effects of environmental pressures and water demand management policies on water demand behaviour of households focusing specifically on water conservation. Unlike other agent based models that deal with domestic water demand (e.g. Athanasiadis et al., 2005 or Galan et al., 2009) this model does not include a statistical or econometric model of consumption and focuses only on the household's water demand behaviour. Water consumption is then estimated using a model specifically developed to simulate demand from the appliance level all the way to the water source (UWOT – presented in the following section). The variables, processes and design

[1] One critically important characteristic of a complex adaptive system (CAS) is that the properties of the system emerge from the characteristics of the individual components, and that these emergent properties can be far more complex than the components (Railsback, 2001).

concepts of the UWAB model are presented using the ODD protocol (Grimm et al., 2006) in the form of a roadmap, following recommendations by Polhill et al. (2008).

UWAB simulates the urban population with each agent representing an urban household. Household agents have parameters that describe their socio-demographic characteristics within the simulated population. The agents are divided into three water user categories (low, average, high) that refer to an idealised "baseline" water demand profile of a given household. This profile is mainly linked to intrinsic motivation and self-determination in the behaviour of the household, where intrinsically motivated and self-determined behaviours are taken to mean those that "represent the prototypes of self-determined or autonomous activities … that people do naturally and spontaneously when they feel free to follow their inner interests." (Deci and Ryan, 2000). In other words, this baseline water demand profile represents a water use "intrinsic tendency" before the household is influenced by water demand management policies, its social network, or the weather. Although clearly this is an idealised assumption, it is backed by a significant evidence base suggesting that people's basic values are in their majority set by the time they reach adulthood, and change relatively little thereafter (Rokeach, 1968, 1973, Inglehart, 1977, 1997, 2008). This was further corroborated by the qualitative socio-psychological research undertaken within the context of this work (Koutiva et al. 2015) where a panel of water users identified as the main driver of their water demand behaviour to be their intrinsic motivation, created from internal individual values, such as environmental and economic values and life experiences. Panel members described their water use behaviours as a result of experiences during childhood. For example "seeing their grand-parents bringing water from the village's central supply" made them aware of the value of water and the necessity to safeguard it in everyday activities. Consequently, this water demand "category" follows a household agent throughout the simulation.

Household agents are assumed to think about (and revise) at regular intervals their *attitude* towards water conservation (positive or negative) and decide about their actual water demand *behaviour*, selecting one out of three (idealised) water conservation "levels" (zero, low or high conservation).

Household agents' attitudes towards water conservation are influenced by their social network and external factors, such as water policies, including for example water price changes and awareness raising campaigns. The interaction between different household agents, influencing their attitude and water demand behaviour, is approached using network theory, as proposed by Sobkowizc (2009). To form a (social) network, household agents are initially linked to each other randomly using either NetLogo's preferential attachment or small-world method (Wilensky, 2005). The network is then expanded using the sum of the difference of the socio-demographic characteristics of the paired household agents as a proxy to the strength of the social links thus allowing for the simulation of the effects of social immediacy (Sobkowizc, 2009).

Household agents with a negative attitude towards water conservation can only select the "zero" water conservation level for their water demand behaviour state. On the other hand, household agents with a positive attitude towards water conservation may choose one out of all three water conservation levels (zero, low or high conservation). Household agents' receive, every three months, water bills. The household agents compare their current water bill with their previous one and decide whether they prefer a higher, lower or the same level of conservation for their water demand behaviour state. This preference is used by the household agents in their water demand behaviour decision procedure. At the end of each time step the UWAB model calculates the number of household agents that have selected each water demand behaviour state. The resulting demand is then calculated using UWOT.

3. The Urban Water Optioneering Tool (UWOT)

UWOT is an urban water cycle model that utilises a bottom up approach, simulating water demand generated by household appliances, aggregating those at the household, neighbourhood and city levels and then routing this demand all the way to the water sources (Rozos and Makropoulos, 2012). UWOT is used in this work to translate water demand behaviour (represented here by the frequency of use of individual household appliances that use water, such as toilets, washing machines, and showers) into domestic water demand.

UWOT's parameterisation required the identification of household appliances and an estimation of their frequency of use for the different water user types and water demand behaviour states (Rozos and Makropoulos, 2013, Beal et al., 2013, Grant, 2006). The appliances' frequencies of use also account for annual and seasonal trends. Seasonal variability is accounted for by changing the frequency of use of appliances that are affected by weather changes such as the shower, the washing machine and outside uses (Rozos and Makropoulos, 2013). Longer term (suprannual) trends were also incorporated across all in-house water appliances to capture the effects of changing quality of life (under the assumption that as quality of life increases so does overall frequency of use of water appliances).

Assigning frequency of uses for different conservation levels is a challenging task. To derive a reasonable estimate, different water uses were divided into two separate categories: uses that cover basic (non-discretional) everyday needs and uses covering discretional functions (Willis et al. 2011). Basic needs include drinking water, sanitation (flushing toilets), bathing (using the hand basin, shower, bath, and washing machine) and kitchen activities (kitchen sink and the dishwasher). Discretionary needs cover non-essential water uses, such as irrigation and outdoor activities. It is of course understood that many basic water needs do include a large discretionary component, such as showering or bathing for relaxing and not for sanitation purposes (Willis et al., 2011). Consequently when exploring the water saving potential of a household, one may also include basic needs to those where water saving is feasible.

We then proceeded to identify the frequencies of use of appliances for both common and decreased water demand by undertaking a questionnaire-based research asking people how often certain appliances are being used in their households and how much they were willing to decrease this use in order to conserve water. The appliances' frequencies of use time series were then entered into UWOT.

4. UWAB and UWOT interaction

UWOT is first setup and run to calculate initial demands and create water billing information. This information is inserted in UWAB which then simulates the evolution of the selection of water demand behaviour states by the household agents. At the end of the UWAB simulation two types of results are available: UWOT results in the form of water demand time series per household type, water user type and water demand behaviour state and UWAB results in the form of number of households time series per household type, water user type and water demand behaviour state.

The 45 time series resulting from UWOT are multiplied with the 45 time series resulting from UWAB and the result is also multiplied with the number of actual households that each household agent represents in order to produce the total monthly domestic water demand. More information regarding the integration of the UWAB and UWOT models to investigate the evolution of domestic water demand in an urban area is given in Chapter 4.

5. Demonstrating the approach: the case of the 1988 – 1994 drought in Athens

The evolution of domestic water demand during the Athens 1988-1994 drought period was used to test the capabilities of the proposed approach. Between 1988 and 1994, a prolonged period of low precipitation (less than 50% of the long term average) in Athens reduced the city's water reserves to such a degree that by the end of 1994, they were barely enough to satisfy the demand of the city for a year (Mamasis and Koutsoyiannis, 2007). The main response, by the Water Company of Athens (EYDAP) to this risk was a substantial increase of water prices, at an average of 240% across all levels of consumption, and extensive water saving awareness campaigns taking place in 1990, 1992 and 1993 (EYDAP, 2009, Kanakoudis, 2008). The (combined) effect of these measures was an approximate 33% drop of domestic water demand, from an average of 150 litres per inhabitant per day in 1989 to 100 litres per inhabitant per day in 1993 (Mamasis and Koutsoyiannis, 2007).

This period was selected as a prime example of the context which the UWAB model was developed to simulate: a situation where an external risk (such as a prolonged drought period) is combined with policy measures and financial incentives, leading to a significant modification of water user behaviour, over a period of several years. Importantly, this is one of the rare cases where data and knowledge exists on the sequence of actions taken and results achieved by the water demand management strategies employed. As such it was selected as a case study that could test the potential of the proposed approach to re-create the social dynamics and resulting demand reductions and provide some insights as to the legitimacy of the conceptualisation and implementation of the UWAB model.

5.1 UWOT setup

Three types of water users (low, average and high) were created in UWOT to simulate the evolution of Athens' domestic water demand. The average water user's baseline water demand per household was identified based on EYDAP's reported mean monthly domestic demand for 1986, which was 125 litres per person per day (EYDAP, 2009) with a standard deviation of 15 litres per person per day that were estimated using a normal distribution of water demand. This calculation was based on a minimum billed water volume, since 1996, of 2 cubic meters per month per water meter (EYDAP pricing policy data, 2013).

It was then assumed that average water users fall within one standard deviation of the mean (between –σ and +σ), corresponding to a 68.2% of the total population with a water demand of 125 litres per person per day. Low water users fall bellow one standard deviation of the mean (all those between –σ and -4σ), corresponding to a 15.9% of the total population with a water demand of 97 litres per person per day. Finally, high water users fall above one standard deviation of the mean (all those between +σ and +4σ), corresponding to the remaining 15.9% of the total population with a water demand of 147 litres per person per day. The water demand for the low and high water user types were estimated by calculating the centre of mass of the surface created by the normal distribution's curve and the corresponding standard deviation line parallel to the y axis.

The seasonal variability and the frequencies of use of the household agents' appliances were based on those used in the study of Rozos and Makropoulos (2013) adjusted to reproduce the different mean monthly water demands of the selected water user types for 1986.

To account for longer term (baseline) trends in water demand during the period in question, a report with water demand projections in Athens, published in 1990 was used. This report (Germanopoulos, 1990) did not include the effects of the drought period and reports an annual increase rate of water demand of about 6% during the 1980s (attributed mainly to an overall increase of the quality of life of Athenians during that decade). In the same report, Germanopoulos (1990) projected that during the 1990s the annual increase rate would be much lower, around 1.30%, mainly due to the projected stabilisation of the quality of life conditions. The above water demand annual increase rates were translated into an increase of the frequency with which households are using each water consuming appliance.

Finally, different time series of frequencies of use were created for all the assumed three water user types and their corresponding water conservation levels (low water user with low, high or no conservation level, average water user with low, high or no conservation level and high water user with low, high or no conservation level). The different conservation levels were created using the results of an online survey, undertaken for the purposes of this work in 2013 (Koutiva and Makropoulos, 2015a). A set of questions was included in the survey specifically regarding the frequency of use of water appliances and the willingness and % of frequency decrease that was acceptable for different levels of water conservation. Since this social research was conducted in 2013, one cannot of course suggest that the replies are fully representative of customs in 1986, but in the absence of other data, these percentages of decrease for low and high conservation levels were utilised in setting up the appliances' frequencies of use for the different conservation levels in our simulation.

Following the setup of the household appliances' frequencies of use for each water demand type and conservation level, UWOT was set to run from 1986 to 1998 on a monthly basis (a total of 156 time steps). An example of the results of UWOT is given in Chapter 7 for households with average water user type per conservation level. These results were used firstly to estimate the water bills per household demand type and secondly to be integrated with the UWAB results to estimate the total mean monthly water demand of Athens population during the period of 1986-1998.

5.2 UWAB implementation

In 1981 Athens had about 850.000 households which increased to about 1.000.000 households by 1991 (ELSTAT, 2012). Consequently, in UWAB, the simulation begins with 930 household agents representing the 930.000 households of Athens. Every twelve steps (i.e. every year with a time step of one month) 25 new household agents, representing 25.000 households, are created to demonstrate the population increase that took place from 1986 to 1998.

The agent variables that need to be set during the UWAB setup include the socio-demographic and the social impact characteristics. These variables characterise the population and remain constant throughout the simulation. Household agents are assigned levels of socio-demographic characteristics consistent with socio-demographic characteristics distribution within the population reported by the Office of National Statistics (ELSTAT, 2012). These include characteristics of education level, age and housing conditions. In addition, an income class categorization was used taking into account both income and occupation (NCSR, 2006).

The effect of the water price changes is usually evaluated using an econometric approach (see Mylopoulos et al., 2004) which can be combined with an ABM approach for evaluating water pricing policies (see Athanasiadis et al., 2005). In this work, UWAB captures the effect on the agents of the information that water price changes and not the effect of the actual change in price. This is because the UWAB model tries to capture the effects of information transmissions regarding water demand policies, drought conditions, social network's attitudes and the impact of this information to the water demand behaviour of the urban household. Additionally, it was concluded by assessing the evolution of water demand and water policies during the drought period and beyond that even though the water prices remained at a high rate, the water consumption increased whilst the drought was over. For this reason, pricing policy is set as an external positive or negative force towards water conservation affecting the social impact exerted on the household agents. An increase or decrease of the water price is assumed to affect the population by adding an external influence parameter (positive or negative respectively) towards water conservation.

From 1986 to 1998, water prices changed eight times, either as a correction of the water price levels (prior to 1990 and after 1993), or as a policy measure directly targeting the issue of the drought during the period 1988-1994 (EYDAP, 2009). The transmission of this information is assumed to start one month prior to the application of the water price change and to keep on affecting the household agent for the next five months, leading to a total of a six months "information effect period" for all price changes. EYDAP records suggest that water prices changed in the following months: 01/07/1986, 01/07/1988, 0101/1990, 01/05/1990, 01/01/1991, 01/01/1992, 01/07/1992 and 01/12/1995.

The variables of water saving awareness campaigns that need to be set are the influence strength (S_{AC}) and the implementation period. The influence strength of a water saving awareness campaign is an experimental variable and was set during the calibration process of the model. There were in all three periods of water saving awareness campaigns for the case in question [01/01/1990 – 31/12/1990], [01/01/1992 – 31/12/1992] and [01/01/1993 – 31/12/1993] (EYDAP, 2009, Kanakoudis, 2008) and these were modelled in this work.

During 1993 authorities increased their efforts to reduce domestic water demand as much as possible. On top of awareness campaigns and water price increases a series of water use restrictions to outside uses and penalties to heavy water users were also introduced (Kanakoudis, 2008). These extra water policies drastically affected Athenians, resulting in a 52% reduction of mean monthly water demand, compared with the expected one (Kanakoudis, 2008). These extra water policies are introduced as two extra dummy parameters that are added to the behavioural intention functions of the water conservation levels during 1993. These dummy parameters increase the probability for high and low water conservation level, thus increasing the behavioural intention of the household and ultimately the probability to conserve water.

Following the setup of the household agents, UWAB is ready to simulate the behaviour of Athens' household agents for the 156 months from 1986 to 1998. UWAB results come in the form of number of household agents per water user category and conservation level (Chapter 7). One of the main results is that, while awareness raising campaigns and price changes were in place, a significant behaviour change was evident towards water conservation for all three water user types.

5.3 Sensitivity analysis and validation of the UWAB – UWOT modelling platform

Finally, the results of the UWAB and UWOT models for the Athens case study are combined, by multiplying the number of households for each water user type and water conservation level with their corresponding water demand. A sensitivity analysis is then performed using eight experimental variables (see Annex I for details): mean strength of influence for household agents and external influence (S), mean strength of influence regarding awareness raising campaigns (S_{AC}), mean strength of influence regarding water price changes (S_{PC}), number of months before and after water price changes that the information is transmitted (M), percentage of initial positive attitudes (%ipa), percentage of external positive attitudes (%epa), volatility of social impact (T) and social network structure.

As proposed by Nikolic et al. (2012), Latin hypercube sampling was used to sample the multidimensional parameter space and create experiments for exploring the sensitivity of the proposed model parameters. One hundred parameter sets were selected and corresponding experiments were created. These experiments were repeated ten times each in order to decrease the influence of outliers on the average result. The mean output of the ten repetitions of each of the one hundred sampled parameter sets was used for the sensitivity analysis of the proposed modelling platform.

The main purpose of model validation in this case is to see if the model adequately recreates real world observations and their oscillations while water policies are in force, and indeed what is the sensitivity of the model's behaviour to changes in key variables. An objective function was used to investigate this, calculating the Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970), as modified by Krause et al. (2005) and Herrera et al. (2010) (see Equation 4-5 included in Chapter 4). The range of the modified Nash – Sutcliffe coefficient lies between 0 (perfect fit) and $+\infty$. Values of more than 1 signify that the mean (median) value of the historical time series is a better predictor than the proposed model. In addition, another objective function, the Mean Absolute Percentage Error (MAPE) (see Equation 4-6 included in Chapter 4), was used for measuring the divergence of the modelled results from the historical values during the intensive water policy response measures period of 1990-1993. The Monte Carlo Analysis Toolbox (Wagener, 2004) was used to perform the sensitivity analysis of the model's experimental variables on these two objective functions. The analysis led to the identification of the value ranges within which the parameters are most identifiable. These value ranges are then used in the model's optimisation procedure as constraints.

The experimental variables were calibrated using a multi-objective genetic algorithm (Deb, 2001) aiming to minimise the two objective functions used in the sensitivity analysis: the Nash-Sutcliffe modified coefficient and the 1990-1993 mean absolute percentage error. Figure 1 presents the resulted Pareto fronts from the multi-objective genetic algorithm for 10, 30, 70 and 100 iterations. Each iteration includes ten different parameter sets and therefore requires UWAB to run for 100, 300, 700 and 1000 times respectively.

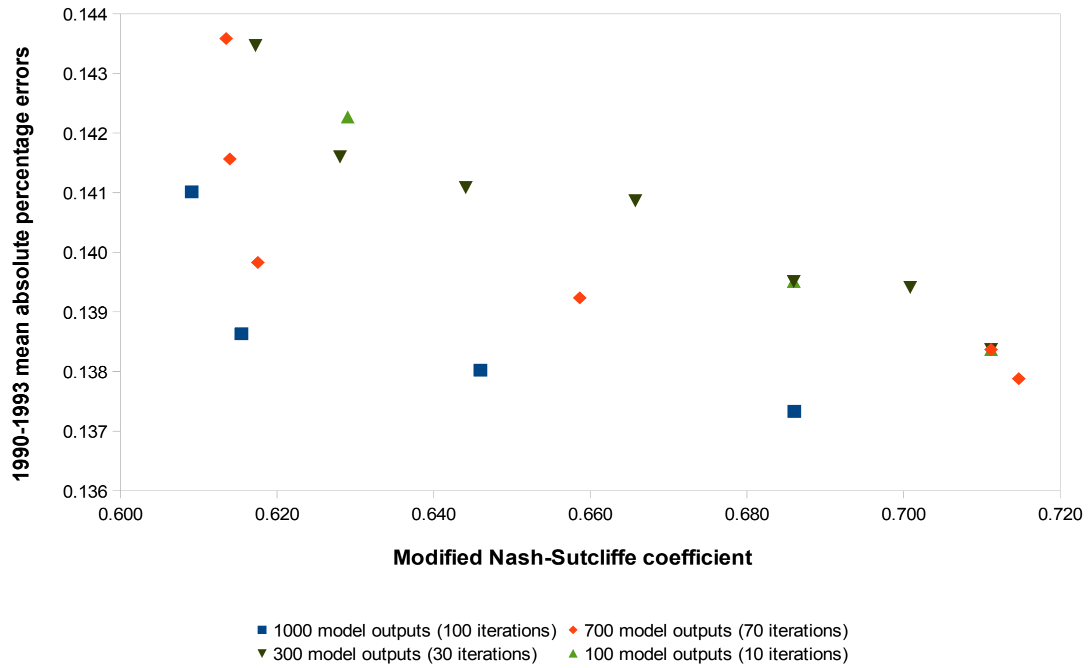


Figure 1. Pareto fronts resulted from the multi-objective algorithm minimising both selected objective functions. Objective functions' results are given for different iteration numbers.

The modelling platform was initialised based on the results of the optimisation process and run 10 times for each optimisation solution. Figure 2 presents the results from the application of the UWAB-UWOT modelling platform to the Athens 1988-1994 drought period.

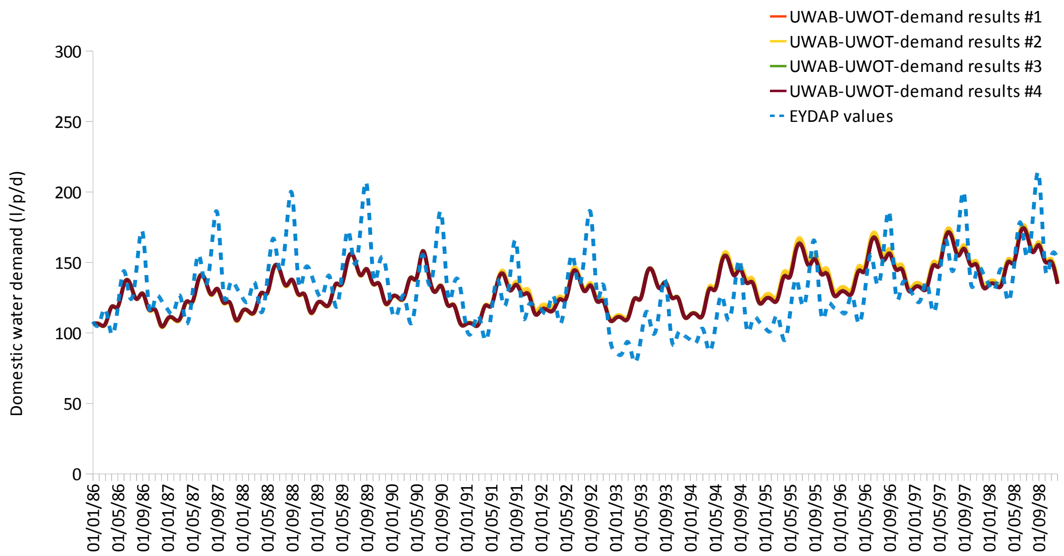


Figure 2. Results of simulated Athens 1988-1994 drought period (blue line: EYDAP historical values)

5.4 Usability of UWAB-UWOT modelling platform in supporting adaptive urban water management

The calibrated UWAB-UWOT modelling platform was then used to assess scenarios of future water demand and create experiments of water demand management strategies assessing their effects on the water system of Athens. Five water demand scenarios were created and assessed using ten decades of net inflows of the reservoirs and a model of the Athens external hydrosystem which was setup in UWOT (Table 1).

Table 1. Water demand scenarios assessment based on the water supply time series

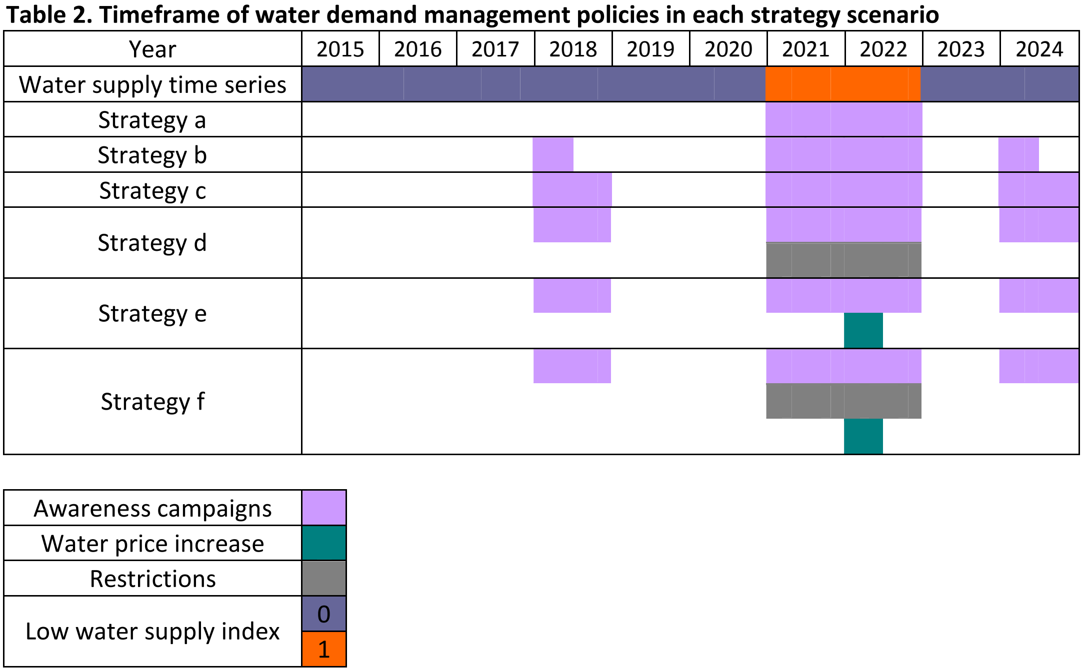
			Water supply time series									
Water demand scenarios	Description	Water demand (hm^3)	1	2	3	4	5	6	7	8	9	10
Scenario 1	Baseline	370	√	√	√	√	√	√	√	√	√	√
Scenario 2	Increase water demand	450	√	√	√	√	√	√	√	√	√	√
Scenario 3	7% population increase	480	√	√	√	+	√	√	√	√	√	√
Scenario 4	12% population increase	500	√	√	√	+	√	√	√	√	√	√
Scenario 5	20% population increase	550	√	√	√	+	√	√	√	√	√	√

√ represents a water demand volume being met
+ represents a water demand volume not met

Those combinations of water demand scenarios and water supply time series that resulted in failures to meet the required demand were selected as candidates for deployment of water demand management strategies (Table 2).

Seven experiments of water demand management strategies were implemented using UWAB. The UWAB model ran ten times without any water demand management strategies in place and the mean value of the results was combined with the results of UWOT. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Table 2. Timeframe of water demand management policies in each strategy scenario



The results of the experiments for the different water demand scenarios suggest that the precautionary use of awareness raising campaigns decreases the probability of unmet demands and highlights the importance of the duration of the campaign as a key factor to its success. Interestingly, the results also suggest that water price change strategies do not achieve a substantially higher decrease than the decrease achieved by awareness raising campaigns strategies only or awareness campaigns and restrictions strategies together.

The results also suggest that although awareness campaigns can minimise the effects of drought events there is a limit to their capacity to manage demands increasing due to longer term drivers such as population increases and long term persistence of drought conditions. Even in this case though the modelling tools developed in this work are useful in identifying the boundaries of the effects of alternative measures including both hard engineering and soft interventions and as such are of direct relevance to water companies and policy makers.

6. Discussion and conclusions

This research focused on the water demand behaviour of urban households and developed an Agent Based Model (UWAB) to “find a micro-macro generative mechanism that can allow explaining the specificity of the case, and … to build upon it realistic scenarios for policy making” (Boero and Scquazoni, 2005). The combination of UWAB with an existing urban water management model (UWOT) allows the estimation of the “macro” mean domestic water demand from the “micro” domestic water demand behaviour of urban households in a way not possible before. As such, the work proposed an alternative novel methodology, tools and modelling framework able to simulating the water demand behaviour of urban households taking into consideration both technical (frequencies of use of different water appliances) and social (influences from social network, policies etc) characteristics of the urban water system. It is argued that the proposed approach can provide new insights for designing and assessing water demand management strategies for cities worldwide.

Εκτεταμένη Περίληψη

1. Εισαγωγή

Το αστικό υδρο-σύστημα είναι ένα πολύπλοκο σύστημα αποτελούμενο από τεχνολογικές (υποδομές ύδρευσης), περιβαλλοντικές (υδατικοί πόροι) και κοινωνικές συνιστώσες (χρήστες νερού). Οι συνιστώσες αυτές αλληλεπιδρούν δυναμικά και συνεχόμενα και οι σχέσεις μεταξύ τους εξελίσσονται στο χρόνο. Η δυναμική φύση της οικιακής ζήτησης νερού αυξάνει την αβεβαιότητα όσον αφορά την συμπεριφορά του συστήματος στην αντιμετώπιση αλλαγών και παρεμβάσεων (House-Peters και Chang, 2011). Στη βιβλιογραφία πλέον παρουσιάζεται μια ολοκληρωμένη, σε επίπεδο συστήματος, προσέγγιση του αστικού κύκλου νερού, προσπαθώντας να διαχειριστεί τόσο την προσφορά όσο και τη ζήτηση, μέσω ενός ενιαίου πλαισίου διαχείρισης (Rozos and Makropoulos, 2013, Behzadian et al, 2014). Ακόμα όμως και αυτές οι πιο ολοκληρωμένες προσεγγίσεις αδυνατούν να προσομοιώσουν ουσιαστικά τον τελικό οικιακό χρήστη νερού.

Δύο από τις κύριες προκλήσεις για την ενσωμάτωση του τελικού οικιακού χρήστη νερού στην προσομοίωση του αστικού κύκλου νερού είναι: (α) η εκτίμηση της συμπεριφοράς των νοικοκυριών όσον αφορά τη ζήτηση νερού και (β) η ποσοτικοποίηση του τρόπου με τον οποίο αυτή η συμπεριφορά επηρεάζεται από τα μέτρα διαχείρισης της οικιακής ζήτησης νερού, όπως εκστρατείες ευαισθητοποίησης και μεταβολές των τιμών του νερού αστικής κατανάλωσης.

Στη παρούσα έρευνα, η συμπεριφορά της ζήτησης νερού των νοικοκυριών προσομοιώνεται χρησιμοποιώντας θεωρίες από τον χώρο της Κοινωνικής Ψυχολογίας, οι οποίες παρέχουν ένα εννοιολογικό μοντέλο για τον τρόπο με τον οποίο η ανθρώπινη συμπεριφορά επηρεάζεται και διαμορφώνεται από τους άλλους (Allport, 1954, Hogg and Vaugnan, 2011) και την πιθανή συσχέτιση ανάμεσα στις στάσεις, στις προθέσεις και στις πραγματικές συμπεριφορές (Ajzen, 1991).

Το περιβάλλον προσομοίωσης, που επιλέχθηκε για την μοντελοποίηση της συμπεριφορά της σχετικής με την οικιακή ζήτηση νερού είναι τα μοντέλα ευφυών πρακτόρων (Agent Based Modelling (ABM)). Τα ABM έχουν την ικανότητα να ποσοτικοποιήσουν αναδυόμενες (bottom-up) συμπεριφορές, προσομοιώνοντας τη δυναμική αλληλεπίδραση μεταξύ της κοινωνικό-οικονομικής συνιστώσας και του αστικού συστήματος νερού και ως εκ τούτου, να αποτελέσουν τον συνδετικό κρίκο στην προσομοίωση του πλήρους κοινωνικό-τεχνικού συστήματος νερού (Wheater et al. 2007, Koutiva and Makropoulos, 2011, Filatova et al., 2013). Τα ABM χρησιμοποιούν ευφυείς πράκτορες, οι οποίοι ορίζονται ως «συστήματα ηλεκτρονικών υπολογιστών που βρίσκονται σε κάποιο περιβάλλον, ικανά για αυτόνομη δράση εντός αυτού του περιβάλλοντος, προκειμένου να επιτύχουν όλους τους στόχους τους» (Wooldridge, 1999). Ουσιαστικά, τα ABM είναι μια μορφή υπολογιστικής κοινωνικής επιστήμης (Gilbert, 2008), με σύνθετες συμπεριφορές σε επίπεδο συστήματος να δημιουργούνται από την αλληλεπίδραση των απλών συνιστωσών του συστήματος.

Στην παρούσα ερευνητική εργασία αναπτύσσουμε ένα εργαλείο ABM, το οποίο ονομάζουμε Urban Water Agents’ Behaviour (UWAB) και το οποίο προσομοιώνει τη συμπεριφορά ενός νοικοκυριού σε σχέση με τη ζήτηση νερού με βάση: (α) τη θεωρία σύνθετων δικτύων (Albert and Barabasi, 2000) που αντιπροσωπεύει τους κοινωνικούς δεσμούς που δύναται να επηρεάσουν την οικιακή ζήτηση νερού (β) τη θεωρία της κοινωνικής επιρροής (Social Impact Theory) (Latane, 1981) για την προσομοίωση της επιρροής που ασκούν πολιτικές και άλλοι εξωτερικοί παράγοντες στη συμπεριφορά των οικιακών χρηστών νερού, (γ) τη θεωρία της σχεδιασμένης συμπεριφοράς (Theory of Planned Behaviour) (Ajzen, 1991) η οποία αναλύει τη συμπεριφορά του οικιακού χρήστη νερού στα συστατικά της με σκοπό τη μοντελοποίηση της πρόθεσης του και (δ) τη στατιστική μηχανική (Shell, 2014) η οποία χρησιμοποιείται για την προσομοίωση της στοχαστικής φύσης της ανθρώπινης συμπεριφοράς.

Η συμπεριφορά των νοικοκυριών σε σχέση με τη ζήτηση νερού και η επιρροή που ασκούν στη συμπεριφορά αυτή πολιτικές διαχείρισης αλλά και περιβαλλοντικές πιέσεις προσομοιώνεται από το μοντέλο UWAB. Στη συνέχεια η συμπεριφορά αυτή μεταφράζεται σε συγκεκριμένη ζήτηση μέσω της προσομοίωση των συσκευών κατανάλωσης νερού ενός νοικοκυριού με το εργαλείο Urban Water Optioneering Tool (UWOT) (Makropoulos et al., 2008). Η σύνδεση του μοντέλου UWAB με το UWOT δημιουργεί την πλατφόρμα μοντελοποίησης UWAB-UWOT. Η πλατφόρμα αυτή εφαρμόζεται ως παράδειγμα στο αστικό σύστημα νερού της Αθήνας. Η βαθμονόμηση και διακρίβωση της πλατφόρμας γίνεται χρησιμοποιώντας μια μεγάλη περίοδο ξηρασίας στην Αθήνα. Η βαθμονομημένη πλατφόρμα χρησιμοποιείται στη συνέχεια για να αξιολογήσει σενάρια διαφορετικών στρατηγικών διαχείρισης της μελλοντικής οικιακής ζήτησης για τη πόλη της Αθήνας.

2. Παρουσίαση του εργαλείου Urban Water Agents’ Behaviour (UWAB)

Το μοντέλο UWAB δημιουργήθηκε, με τη χρήση της γλώσσας προγραμματισμού ευφυών πρακτόρων NetLogo (Wilensky, 1999). Σε αντίθεση με άλλα μοντέλα ευφυών πρακτόρων που υπολογίζουν τη ζήτηση νερού οικιακής χρήσης (π.χ. Athanasiadis et al., 2005, Galan et al., 2009), το μοντέλο αυτό δεν περιλαμβάνει στατιστική ή οικονομετρική εκτίμηση της κατανάλωσης και επικεντρώνεται μόνο στην συμπεριφορά ενός νοικοκυριού η οποία δημιουργεί τη ζήτηση. Στη συνέχεια, η κατανάλωση νερού εκτιμάται χρησιμοποιώντας ένα μοντέλο που έχει αναπτυχθεί ειδικά για την προσομοίωση της ζήτησης, προσομοιώνοντας την κατανάλωση νερού των συσκευών ενός νοικοκυριού (το UWOT - παρουσιάζεται στην επόμενη ενότητα). Οι μεταβλητές, οι διαδικασίες και οι έννοιες του σχεδιασμού του μοντέλου UWAB παρουσιάζονται ακολουθώντας το πρωτόκολλο ODD (Grimm et al., 2006) όπως εισηγούνται οι Polhill et al. (2008).

Το UWAB επικεντρώνεται στο αστικό πληθυσμό με τους ευφυείς πράκτορες να αντιπροσωπεύουν τα αστικά νοικοκυριά. Τα νοικοκυριά διαιρούνται σε τρεις κατηγορίες οικιακών χρηστών νερού (χαμηλός, μέσος, υψηλός) οι οποίοι αναφέρονται σε ένα εξιδανικευμένο «βασικό» προφίλ οικιακής ζήτησης νερού ενός νοικοκυριού. Αυτό το προφίλ οικιακής ζήτησης νερού αποτελεί μια "εγγενή τάση" πριν να επηρεαστεί το νοικοκυριό από πολιτικές διαχείρισης, κοινωνικές επαφές, ή τις καιρικές συνθήκες. Αν και σαφώς αυτό είναι μια εξιδανικευμένη υπόθεση εργασίας, υποστηρίζεται από στοιχεία που δείχνουν ότι οι βασικές αξίες των ανθρώπων παραμένουν στην πλειοψηφία τους, όπως διαμορφώθηκαν μέχρι την ενηλικίωση και αλλάζουν σχετικά λίγο στη συνέχεια (Rokeach, 1968, 1973, Inglehart, 1977, 1997, 2008). Αυτό επιβεβαιώνεται περαιτέρω από την ποιοτική κοινωνικό-ψυχολογική έρευνα που εφαρμόστηκε στο πλαίσιο αυτής της έρευνας (Koutiva et al., 2015), όπου μια ομάδα χρηστών νερού εντόπισε ως βασικό άξονα επιρροής της οικιακής ζήτησης νερού τα εγγενή κίνητρά τους, που δημιουργήθηκαν από εσωτερικές ατομικές αξίες, όπως η περιβαλλοντική συνείδηση καθώς και από τις εμπειρίες ζωής κατά τη διάρκεια της παιδικής ηλικίας. Για παράδειγμα, "βλέποντας τον παππού και τους γονείς να φέρνουν νερό από την κεντρική βρύση του χωριού" τους έκανε να συνειδητοποιήσουν την αξία του νερού και την ανάγκη να διασφαλιστεί η επάρκεια του. Κατά συνέπεια, αυτή η κατηγοριοποίηση ακολουθεί έναν ευφυή πράκτορα σε όλη την προσομοίωση.

Οι πράκτορες αποφασίζουν και αναθεωρούν σε τακτά χρονικά διαστήματα τη στάση τους απέναντι στην εξοικονόμηση νερού (θετική ή αρνητική) και αποφασίζουν σχετικά με την οικιακή ζήτηση νερού τους, επιλέγοντας ένα από τρία (εξιδανικευμένα) επίπεδα εξοικονόμησης νερού (μηδενική, χαμηλή ή υψηλή εξοικονόμηση).

Οι στάσεις των πρακτόρων ως προς την εξοικονόμηση νερού επηρεάζεται από τις κοινωνικές τους επαφές και άλλους εξωτερικούς παράγοντες, όπως είναι οι πολιτικές διαχείρισης που συμπεριλαμβάνουν τις μεταβολές της τιμής του νερού και τις εκστρατείες ευαισθητοποίησης. Οι εκστρατείες ευαισθητοποίησης αποτελούν μία θετική δύναμη επιρροής της στάσης ενός νοικοκυριού απέναντι στην εξοικονόμηση νερού. Η μεταβολή της τιμής του νερού αποτελεί μια ακόμα εξωτερική (θετική ή αρνητική) επίδραση στη στάση ενός νοικοκυριού απέναντι στην εξοικονόμηση νερού. Είναι σύνηθες στην επιστημονική βιβλιογραφία να αξιολογούνται οι επιδράσεις των αλλαγών της τιμής του νερού στην οικιακή ζήτηση νερού χρησιμοποιώντας οικονομετρικές προσεγγίσεις (Mylopoulos et al., 2004) οι οποίες δύναται να συνδυαστούν με μοντέλα ευφυών πρακτόρων για την αξιολόγηση των πολιτικών τιμολόγησης του νερού (Athanasiadis et al., 2005). Το UWAB ακολουθεί μια διαφορετική προσέγγιση και αξιολογεί μόνο την επίδραση της πληροφορίας της αλλαγής της τιμής και της πληροφορίας υπέρ της εξοικονόμησης που προέρχεται από μια εκστρατεία ευαισθητοποίησης, στην συμπεριφορά οικιακής ζήτησης νερού.

Η αλληλεπίδραση μεταξύ των πρακτόρων προσεγγίζεται με τη χρήση της θεωρίας των δικτύων, όπως προτείνεται από τον Sobkowizc (2009). Για να σχηματιστεί το δίκτυο επιρροής, οι πράκτορες συνδέονται μεταξύ τους επιλέγοντας ένα από τα δύο υποδείγματα δικτύων που υποστηρίζει η NetLogo (preferential attachment or small-world (Wilensky, 2005)). Μετά το δίκτυο επιρροής επεκτείνεται χρησιμοποιώντας τη διαφορά των κοινωνικό-δημογραφικών χαρακτηριστικών μεταξύ των πρακτόρων και υπολογίζοντας με αυτόν τον τρόπο τη δύναμη των κοινωνικών δεσμών (Sobkowizc, 2009).

Οι πράκτορες με αρνητική στάση απέναντι στην εξοικονόμηση νερού δύναται να επιλέξουν μόνο το επίπεδο «μηδενικής» εξοικονόμησης νερού. Από την άλλη πλευρά, οι πράκτορες με θετική στάση απέναντι στην εξοικονόμηση νερού δύναται να επιλέξουν ένα από τα τρία επίπεδα εξοικονόμησης νερού (μηδενική, χαμηλή ή υψηλή). Αρχικά, οι πράκτορες λαμβάνουν, κάθε τρεις μήνες, λογαριασμούς νερού. Μετά συγκρίνουν τον τρέχοντα λογαριασμό με αυτόν της προηγούμενης περιόδου και αποφασίζουν αν θα προτιμήσουν μια υψηλότερη, χαμηλότερη ή ίδιου επιπέδου εξοικονόμηση ζήτησης. Η προτίμηση αυτή χρησιμοποιείται από τους πράκτορες στη διαδικασία λήψης της τελικής απόφασης συμπεριφοράς τους. Οι διαδικασίες που ακολουθούνται από τους πράκτορες παρουσιάζονται και αναλύονται περαιτέρω στο Κεφάλαιο 4.

Στο τέλος του κάθε χρονικού βήματος το μοντέλο UWAB υπολογίζει τον αριθμό των πρακτόρων που έχουν επιλέξει κάθε ένα από τα επίπεδα εξοικονόμησης (μηδενική, χαμηλή, υψηλή) ανά κατηγορία οικιακής ζήτησης νερού. Για τον υπολογισμό της τελικής ζήτησης το αποτέλεσμα αυτό συνδυάζεται με τον μοντέλο UWOT.

3. Παρουσίαση του Urban Water Optioneering Tool (UWOT)

Το UWOT είναι ένα μοντέλο προσομοίωσης του αστικού κύκλου του νερού που χρησιμοποιεί μια αναδυόμενη (bottom-up) προσέγγιση, προσομοιώνοντας τη ζήτηση νερού που παράγεται από τις οικιακές συσκευές, συγκεντρώνοντας τις ζητήσεις σε οικιακό και αστικό επίπεδο και, στη συνέχεια, δρομολογώντας αυτή τη ζήτηση από την οικία μέχρι την πηγή (Rozos and Makropoulos, 2012). Το UWOT χρησιμοποιείται για να μεταφράσει τη συμπεριφορά σε σχέση με το νερό (που αντιπροσωπεύεται εδώ από τη συχνότητα χρήσης των οικιακών συσκευών που χρησιμοποιούν το νερό, όπως τουαλέτες, πλυντήρια, και ντους) σε τελική ζήτηση νερού οικιακής χρήσης.

Η παραμετροποίηση του UWOT απαιτεί την εκτίμηση της συχνότητας χρήσης των οικιακών συσκευών για τις διάφορες κατηγορίες των οικιακών χρηστών νερού και για τα διάφορα επίπεδα εξοικονόμησης νερού (Rozos and Makropoulos, 2013, Beal et al., 2013, Grant, 2006). Οι συχνότητες χρήσης των συσκευών περιλαμβάνουν επίσης εποχιακές αλλά και υπερετήσιες μεταβολές. Η εποχιακή μεταβλητότητα σχετίζεται με την αλλαγή της συχνότητας χρήσης των συσκευών που επηρεάζονται από τις καιρικές αλλαγές, όπως το ντους, το πλυντήριο και οι εξωτερικές χρήσεις (Rozos and Makropoulos, 2013). Η υπερετήσια τάση ενσωματώνεται σε όλες τις συσκευές του νερού για να αποτυπώσει τα αποτελέσματα της μεταβολής της ποιότητας ζωής (με την παραδοχή ότι όσο η ποιότητα ζωής αυξάνει τόσο αυξάνει και η συχνότητα χρήσης των συσκευών).

Η μεταβολή της συχνότητας χρήσης των συσκευών για τα διαφορετικά επίπεδα εξοικονόμησης νερού είναι δύσκολο να προσεγγιστεί λόγω κυρίως της ενσωμάτωσης μη βασικών αναγκών νερού στην οικιακή ζήτηση νερού (Willis et al., 2011). Οι βασικές ανάγκες περιλαμβάνουν το πόσιμο νερό, την υγιεινή (τουαλέτες), την καθαριότητα (χρησιμοποιώντας τον νιπτήρα, το ντους, τη μπανιέρα, και το πλυντήριο ρούχων) και τις δραστηριοτήτων της κουζίνας (χρησιμοποιώντας το νεροχύτη και το πλυντήριο πιάτων). Οι μη βασικές ανάγκες περιλαμβάνουν την άρδευση και τις υπαίθριες δραστηριότητες καθώς επίσης και ένα ποσοστό των βασικών αναγκών όπως πχ το μπάνιο για χαλάρωση (Willis et al., 2011). Κατά συνέπεια, κατά τη διερεύνηση των δυνατοτήτων ενός νοικοκυριού για εξοικονόμηση νερού είναι δυνατόν να συμπεριληφθούν και συχνότητες χρήσης των συσκευών που καλύπτουν βασικές ανάγκες.

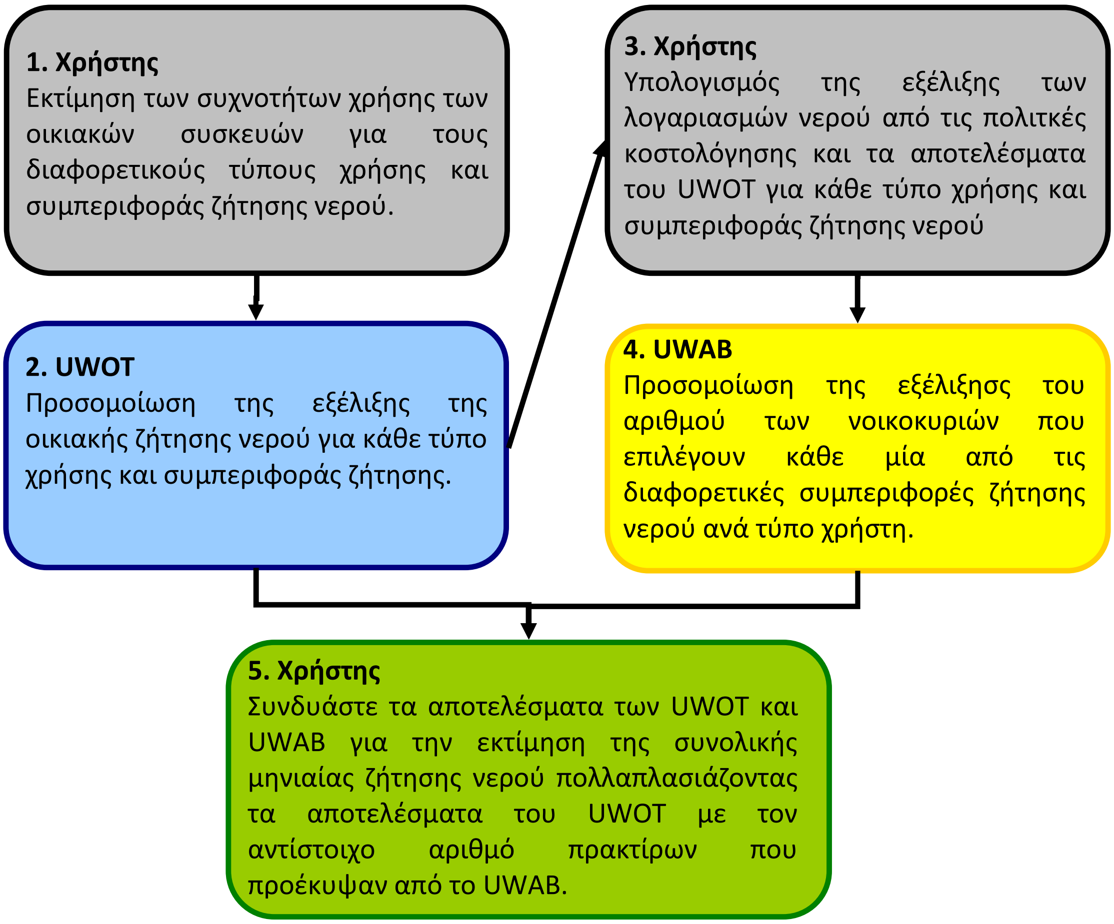
Στα πλαίσια του προσδιορισμού της μείωσης των συχνοτήτων χρήσης των συσκευών νερού για τον προσδιορισμό της μείωσης της οικιακής ζήτησης νερού για το κάθε ένα επίπεδο εξοικονόμησης, σχεδιάστηκε και υλοποιήθηκε ειδικό ερωτηματολόγιο στο διαδίκτυο ζητώντας από τους ερωτώμενους τις συχνότητες χρήσης των διαφόρων συσκευών νερού σε διαφορετικές συνθήκες εξοικονόμησης (Koutiva and Makropoulos, 2015a).

4. Δημιουργία της πλατφόρμας μοντελοποίησης UWAB-UWOT

Το UWOT αρχικά παραμετροποιείται και προσομοιώνει την εξέλιξη της οικιακής ζήτησης νερού δημιουργώντας λογαριασμούς νερού που λαμβάνουν αρχικά οι πράκτορες. Η πληροφορία αυτή εισάγεται στο UWAB το οποίο προσομοιώνει την εξέλιξη της συμπεριφοράς της οικιακής ζήτησης νερού των πρακτόρων. Στο τέλος της προσομοίωσης του UWAB, υπάρχουν δύο είδη αποτελεσμάτων: (α) τα αποτελέσματα του UWOT με τη μορφή χρονοσειρών ζήτησης νερού ανά τύπο νοικοκυριού, και επίπεδο εξοικονόμησης νερού και (β) τα αποτελέσματα του UWAB με τη μορφή χρονοσειρών αριθμού πρακτόρων ανά τύπο νοικοκυριού και επίπεδο εξοικονόμησης νερού.

Σαράντα πέντε χρονοσειρές προκύπτουν από τα δύο μοντέλα, ο πολλαπλασιασμός των οποίων και η αναγωγή του αποτελέσματος στον αριθμό των νοικοκυριών που αντιπροσωπεύει ο κάθε πράκτορας, έχουν ως αποτέλεσμα την παραγωγή της τελικής συνολικής χρονοσειράς με τη μηνιαία ζήτηση νερού οικιακής χρήσης.

Το Σχήμα 1 παρουσιάζει ένα διάγραμμα σύνδεσης των μοντέλων UWAB και UWOT για τη διερεύνηση της εξέλιξης της οικιακής ζήτησης νερού σε μια αστική περιοχή.



Σχήμα 1. Διάγραμμα σύνδεσης των εργαλείων UWAB-UWOT

5. Το αστικό υδατικό σύστημα της Αθήνας

Το αστικό υδατικό σύστημα της Αθήνας, καθώς και οι ιδιαιτερότητες του κατά τη διάρκεια της περιόδου ξηρασίας της Αθήνας μεταξύ του 1988 και του 1994, επιλέχθηκε για να διακριβωθεί το μοντέλο UWAB. Ο βασικός λόγος αυτής της επιλογής έγκειται στο γεγονός ότι κατά την περίοδο αυτή ένας εξωτερικός κίνδυνος (μια παρατεταμένη περίοδος ξηρασίας) συνδυάζεται με μέτρα πολιτικής διαχείρισης, οδηγώντας σε μια σημαντική τροποποίηση της συμπεριφοράς των χρηστών νερού. Ως εκ τούτου, αποτελεί ιδανική μελέτη περίπτωσης για να δοκιμάσει τις δυνατότητες της προτεινόμενης προσέγγισης. Το διακριβωμένο μοντέλο χρησιμοποιείται στη συνέχεια για τον προσδιορισμό των επιπτώσεων διαφορετικών μελλοντικών στρατηγικών διαχείρισης της οικιακής ζήτησης στην Αθήνα.

5.1 Εφαρμογή UWOT

Τρεις τύποι χρηστών νερού (χαμηλή, μέση και υψηλή), δημιουργήθηκαν στο UWOT για να προσομοιώσουν την εξέλιξη της οικιακής ζήτησης νερού στην Αθήνα. Ο μέσος χρήστης νερού προσδιορίστηκε με βάση τα δεδομένα της ΕΥΔΑΠ στα 125 λίτρα ανά άτομο ανά ημέρα το 1986 (ΕΥΔΑΠ, 2009) με τυπική απόκλιση στα 15 λίτρα ανά άτομο ανά ημέρα. Η τυπική απόκλιση εκτιμήθηκε με την παραδοχή ότι η ζήτηση νερού ακολουθεί μια κανονική κατανομή με ελάχιστο τιμολογούμενο όγκο νερού, τα 2 κυβικά μέτρα ανά μήνα (στοιχεία της τιμολογιακής πολιτικής της ΕΥΔΑΠ, 2013).

Η ζήτηση νερού υπολογίζεται από το κέντρο μάζας της επιφάνειας που δημιουργείται από την καμπύλη της κανονικής κατανομής και την αντίστοιχη τυπική απόκλιση. Ο μέσος χρήστης ορίζεται από –σ έως +σ, ο χαμηλός χρήστης από –σ έως και -4σ και ο υψηλός από τη +σ έως και +4σ.

Η εποχική διακύμανση και οι συχνότητες χρήσης των συσκευών βασίστηκαν σε εκείνες που χρησιμοποιούνται στη μελέτη των Rozos and Makropoulos (2013) αλλαγμένες κατά τέτοιο τρόπο ώστε να αναπαράγουν τις διαφορετικές μέσες μηνιαίες τιμές για το 1986.

Η ετήσια εξέλιξη της οικιακής ζήτησης νερού βασίστηκε στη μελέτη του Γερμανόπουλου (1990) η οποία δεν περιλαμβάνει τα αποτελέσματα της περιόδου ξηρασίας και αναφέρει ένα ετήσιο ρυθμό αύξησης της οικιακής ζήτησης νερού της τάξης του 6% κατά τη διάρκεια της δεκαετίας του 1980 (η οποία οφείλεται κυρίως στη συνολική αύξηση της ποιότητας της ζωής των Αθηναίων κατά τη διάρκεια αυτής της δεκαετίας). Στην ίδια έκθεση, προβλέπεται ότι κατά τη διάρκεια της δεκαετίας του 1990 ο ετήσιος ρυθμός αύξησης θα είναι πολύ χαμηλότερος, γύρω στο 1,30%, κυρίως λόγω της προβλεπόμενης σταθεροποίησης της ποιότητας των συνθηκών ζωής. Οι παραπάνω ετήσιοι ρυθμοί αύξησης έχουν ενσωματωθεί στις συχνότητες χρήσης των συσκευών νερού.

Τέλος, οι διαφορετικές χρονοσειρές των συχνοτήτων της χρήσης δημιουργήθηκαν για όλους τους τύπους χρηστών νερού και τα επίπεδα εξοικονόμησης νερού (χαμηλός χρήστης με χαμηλή, υψηλή ή μηδενική εξοικονόμηση, μέσος χρήστης με χαμηλή, υψηλή ή μηδενική εξοικονόμηση και υψηλός χρήστης με χαμηλή, υψηλή ή μηδενική εξοικονόμηση). Τα διαφορετικά επίπεδα εξοικονόμησης υπολογίστηκαν χρησιμοποιώντας τα αποτελέσματα του διαδικτυακού ερωτηματολογίου που πραγματοποιήθηκε το 2013.

Μετά τη ρύθμιση των συχνοτήτων χρήσης των οικιακών συσκευών για κάθε τύπο ζήτησης νερού και επίπεδο εξοικονόμησης, το UWOT προσομοιώνει την εξέλιξη της ζήτησης νερού από το 1986 έως το 1998 με μηνιαίο βήμα (συνολικά 156 χρονικά βήματα).

5.2 Εφαρμογή UWAB

Το 1981 η Αθήνα είχε περίπου 850.000 νοικοκυριά τα οποία αυξήθηκαν σε περίπου 1.000.000 νοικοκυριά το 1991 (ΕΛ.ΣΤΑΤ, 2012). Κατά συνέπεια, στο μοντέλο UWAB, η προσομοίωση αρχίζει με 930 πράκτορες, αντιπροσωπεύει τα 930.000 νοικοκυριά της Αθήνας. Κάθε δώδεκα βήματα (δηλαδή κάθε χρόνο με ένα χρονικό βήμα να ισούται με ένα μήνα) 25 νέοι πράκτορες δημιουργούνται, αντιπροσωπεύοντας 25.000 νοικοκυριά, υπολογίζοντας έτσι την αύξηση του πληθυσμού της Αθήνας από το 1986 έως το 1998.

Το μοντέλο UWAB παραμετροποιείται ρυθμίζοντας τα κοινωνικό-δημογραφικά χαρακτηριστικά των πρακτόρων με βάση την κατανομή τους στον πραγματικό πληθυσμό σύμφωνα με τα δεδομένα της Εθνικής Στατιστικής Υπηρεσίας (ΕΛΣΤΑΤ, 2012) για το επίπεδο εκπαίδευσης, την ηλικία και τις συνθήκες διαμονής. Επιπλέον, η εισοδηματική τάξη κατηγοριοποιήθηκε χρησιμοποιώντας το εισόδημα και την εργασία βασιζόμενη σε σχετική εθνική μελέτη (ΕΚΕΦΕ, 2006).

Από το 1986 έως το 1998, οι τιμές του νερού μεταβλήθηκαν οκτώ φορές, είτε διορθώνοντας τα επίπεδα των τιμών του νερού (πριν από το 1990 και μετά το 1993), ή ως μέτρο διαχείρισης της οικιακής ζήτησης νερού που απευθυνόταν άμεσα στην αντιμετώπιση της ξηρασίας κατά την περίοδο 1988-1994 (ΕΥΔΑΠ, 2009). Επίσης, κατά τη διάρκεια της ίδιας περιόδου εφαρμόστηκαν τρεις εκστρατείες ευαισθητοποίησης του κοινού οι οποίες είχαν ως στόχο την αντιμετώπιση της ξηρασίας της περιόδου 1988-1994 (ΕΥΔΑΠ, 2009, Kanakoudis, 2008). Τέλος, το 1993 οι αρχές έκριναν ότι χρειαζόταν μεγαλύτερη εξοικονόμηση νερού και εφάρμοσαν περιορισμούς χρήσης νερού στους εξωτερικούς χώρους (πότισμα, πλύσιμο αυτοκινήτου, πλήρωση πισίνας κ.α.) (Kanakoudis, 2008). Η εφαρμογή των παραπάνω μέτρων διαχείρισης της οικιακής ζήτησης νερού είχε ως αποτέλεσμα τη μείωση κατά 52% της μέσης μηνιαίας οικιακής ζήτησης (Kanakoudis, 2008).

Μετά την ολοκλήρωση της παραμετροποίησης του UWAB, οι πράκτορες καλούνται να προσομοιώσουν την συμπεριφορά των Αθηναϊκών νοικοκυριών για 156 μήνες, από το 1986 έως το 1998. Τα αποτελέσματα του UWAB έχουν τη μορφή χρονοσειρών αριθμού πρακτόρων ανά τύπο ζήτησης νερού και επίπεδο εξοικονόμησης.

6. Ανάλυση ευαισθησίας και βαθμονόμηση της πλατφόρμας μοντελοποίησης UWAB - UWOT

Στη συγκεκριμένη μελέτη περίπτωσης, τα αποτελέσματα αποτελούν μία εκτίμηση της συνολικής μέσης μηνιαίας ζήτησης νερού της Αθήνας για την περίοδο 1986-1998. Σκοπός αυτής της εκτίμησης είναι να ελεγχθεί η ικανότητα της προτεινόμενης πλατφόρμας να αναδημιουργήσει την εξέλιξη της ζήτησης νερού από το 1986 έως το 1998 υπολογίζοντας έτσι την επίδραση των διαφόρων μέτρων διαχείρισης της οικιακής ζήτησης νερού στην συμπεριφορά των νοικοκυριών.

Η τελική ζήτηση υπολογίζεται με πολλαπλασιασμό του αριθμού των νοικοκυριών για κάθε τύπο ζήτησης νερού και επίπεδο εξοικονόμησης (UWAB) με την αντίστοιχη ζήτηση νερού (UWOT). Οκτώ πειραματικές μεταβλητές χρησιμοποιούνται για την ανάλυση ευαισθησίας του μοντέλου (δίνονται στο Annex I και αναλύονται στο Κεφάλαιο 6).

Η ανάλυση ευαισθησίας χρησιμοποιεί τη μέθοδο δειγματοληψίας του Λατινικού Υπερκύβου, όπως προτείνεται από τον Nikolic et al. (2012) για την ανάλυση ευαισθησίας μοντέλων ευφυών πρακτόρων. Εκατό σύνολα παραμέτρων επιλέχθηκαν και δημιουργούνται τα αντίστοιχα πειράματα. Αυτά τα πειράματα επαναλήφθηκαν δέκα φορές το καθένα, προκειμένου να μειωθεί η επιρροή τυχαίων ακραίων τιμών στο αποτέλεσμα. Το αποτέλεσμα εκτιμήθηκε ως η μέση τιμή των δέκα επαναλήψεων του καθενός από τα εκατό σύνολα παραμέτρων που χρησιμοποιήθηκαν για την ανάλυση ευαισθησίας της προτεινόμενης πλατφόρμας μοντελοποίησης.

Ως αντικειμενικές συναρτήσεις για την ανάλυση ευαισθησίας χρησιμοποιήθηκαν (i) ο συντελεστής Nash-Sutcliffe (Nash και Sutcliffe, 1970), όπως τροποποιήθηκε από τους Krause et al. (2005) και Herrera et al. (2010) (Εξίσωση 1) (βλέπε Κεφάλαιο 4) και (ii) το μέσο απόλυτο ποσοστιαίο σφάλμα (Mean Absolute Percentage Error, MAPE) (Εξίσωση 2) (βλέπε Κεφάλαιο 4).

$$NS\,modified\,(pars_k) = \frac{\sum_{simulation\,start}^{simulation\,end} \left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}} \right)^2}{\sum_{simulation\,start}^{simulation\,end} \left(\frac{E_{WD_i} - \overline{E}_{WD_i}}{\overline{E}_{WD_i}} \right)^2} \qquad \text{Εξίσωση 1}$$

$$MAPE\,(pars_k) = \frac{\left| \sum_{January}^{December} \left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}} \right) \right|}{total\ number\ of\ months} \qquad \text{Εξίσωση 2}$$

όπου,

k ορίζει το σύνολο των παραμέτρων που εξετάζεται (≥ 0)

i ορίζει το αποτέλεσμα του χρονικού βήματος (μήνα) i

j ορίζει το χρονικό βήμα σε μήνες πχ j = μήνας 12 έως 30, συνολικός αριθμός μηνών = 18)

M_{WDi} ορίζει τα αποτελέσματα της προσομοίωσης για το μήνα i,

E_{WDi} ορίζει τις ιστορικές τιμές του μήνα i

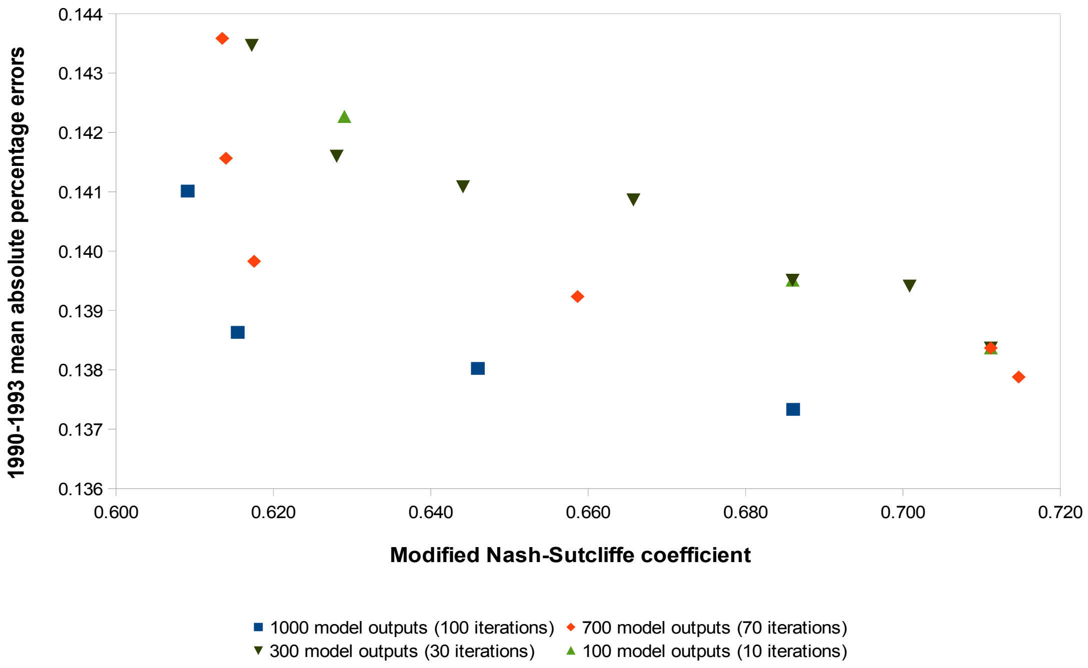
$\overline{E}_{WD_i}$ ορίζει τη μέση ιστορική οικιακή ζήτηση για το μήνα I και

parsk ορίζει το σύνολο των παραμέτρων k, όπως αυτά έχουν επιλεχτεί με τη χρήση της διαδικασίας του Λατινικού Υπερκύβου.

Οι συναρτήσεις αυτές υπολογίζουν την επίδοση του μοντέλου (δηλ. την απόκλιση των αποτελεσμάτων από τις ιστορικές τιμές κατά τη διάρκεια εφαρμογής των μέτρων διαχείρισης της αστικής ζήτησης κατά τους μήνες της περιόδου 1990-1993) για διαφορετικές τιμές των πειραματικών μεταβλητών.

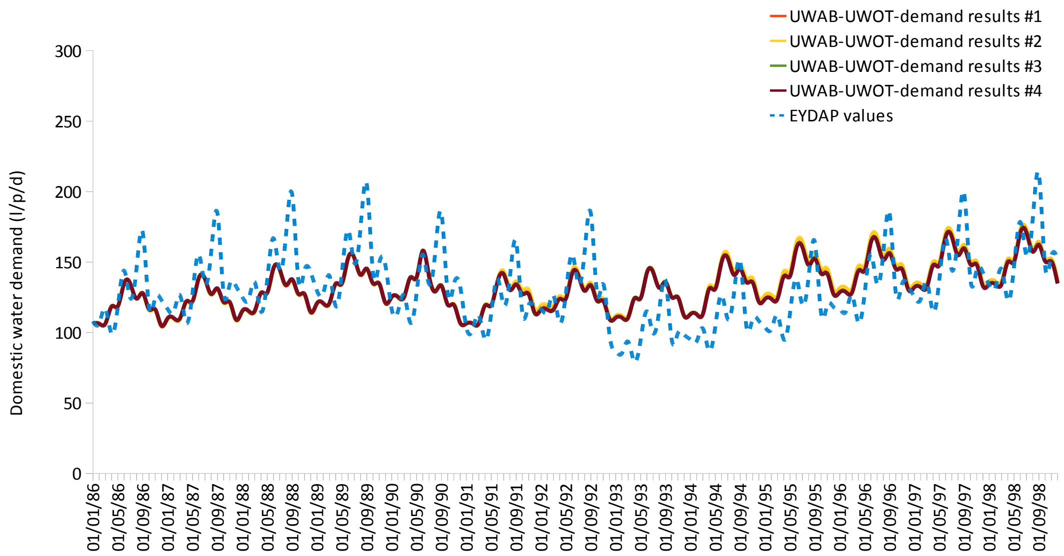
Για την υλοποίηση της ανάλυσης ευαισθησίας των πειραματικών μεταβλητών χρησιμοποιήθηκε το Monte Carlo Analysis Toolbox (Wagener, 2004) και η ανάλυση οδήγησε στην επιλογή ενός εύρους τιμών οι οποίες χρησιμοποιήθηκαν στη διαδικασία βαθμονόμησης της πλατφόρμας ως περιορισμοί.

Οι πειραματικές μεταβλητές βαθμονομούνται με τη χρήση πολυκριτηριακού γενετικού αλγόριθμου (Deb, 2001) με στόχο να ελαχιστοποιηθούν οι δύο αντικειμενικές συναρτήσεις που χρησιμοποιούνται στην ανάλυση ευαισθησίας. Το Σχήμα 2 παρουσιάζει ένα μέτωπο Pareto για 10, 30, 70 και 100 επαναλήψεις του αλγόριθμου βελτιστοποίησης, με κάθε επανάληψη να περιλαμβάνει δέκα διαφορετικά σύνολα παραμέτρων και, ως εκ τούτου 100, 300, 700 και 1000 επαναλήψεις του UWAB αντίστοιχα (βλέπε Κεφάλαιο 7).



Σχήμα 2. Μέτωπο Pareto για 10, 30, 70 και 100 επαναλήψεις του αλγόριθμου βελτιστοποίησης ελαχιστοποιώντας και τις δύο αντικειμενικές συναρτήσεις.

Η βαθμονομημένη πλατφόρμα μοντελοποίησης UWAB-UWOT παραμετροποιήθηκε με βάση τα αποτελέσματα της βελτιστοποίησης και έτρεξε για 10 φορές για κάθε ένα διαφορετικό σύνολο παραμέτρων. Το Σχήμα 3 παρουσιάζει τα αποτελέσματα από την εφαρμογή των παραμέτρων που προέκυψαν από τις 100 επαναλήψεις του αλγόριθμου βελτιστοποίησης στην UWAB-UWOT πλατφόρμα για την εξέλιξη της οικιακής ζήτησης κατά την περίοδο ξηρασίας στην Αθήνα.



Σχήμα 3. Αποτελέσματα μοντελοποίησης οικιακής ζήτησης για την περίοδο ξηρασίας της Αθήνας 1988-1994 (μπλε διακεκομμένη γραμμή: Ιστορικές τιμές αστικής ζήτησης από την ΕΥΔΑΠ)

Τα αποτελέσματα δείχνουν ότι παρά τους περιορισμούς το εργαλείο αναπαράγει επαρκώς την παρατηρούμενη συμπεριφορά του σύνθετου αστικού συστήματος νερού της Αθήνας. Η πλατφόρμα παρόλο που περιέχει αρκετές απλουστευμένες υποθέσεις (Galan et al., 2009) επιτρέπει στον πληθυσμό των ευφυών πρακτόρων να αντιδρά ακολουθώντας μια «κοινή λογική», δηλαδή επανεξετάζοντας την εξοικονόμηση νερού εάν λάβει σήματα από εκστρατείες ευαισθητοποίησης και την ξεχνά, επιστρέφοντας στην κοινή του χρήση, όταν οι πολιτικές παύουν να υφίστανται. Αυτή η «λογική» αλληλουχία στα αποτελέσματα του μοντέλου μπορεί να εκληφθεί και ως επαλήθευση (Crooks et al., 2008). Αυτή η επαλήθευση δεν είναι σίγουρα αρκετή για ένα μοντέλο πχ υδραυλικής προσομοίωσης, εντούτοις, είναι αρκετή για τις μεθόδους κοινωνικής προσομοίωσης που απαιτούνται για να εξεταστεί η επίδραση των στρατηγικών διαχείρισης της οικιακής ζήτησης νερού (Nikolic et al., 2013).

7. Χρήση της UWAB-UWOT πλατφόρμας προσομοίωσης για την υποστήριξη της προσαρμοστικής διαχείρισης του αστικού συστήματος νερού

Η βαθμονομημένη πλατφόρμα μοντελοποίησης UWAB-UWOT χρησιμοποιήθηκε για να αξιολογήσει τα σενάρια της μελλοντικής ζήτησης νερού δημιουργώντας πειράματα στρατηγικών διαχείρισης της οικιακής ζήτησης νερού και αξιολογώντας την επιρροή που ασκούν στο αστικό σύστημα νερού της Αθήνας. Πέντε σενάρια μελλοντικής οικιακής ζήτησης νερού δημιουργήθηκαν και αξιολογήθηκαν με τη χρήση δέκα χρονοσειρών δεκαετίας καθαρών εισροών στους ταμιευτήρες του αστικού συστήματος νερού της Αθήνας και χρησιμοποιώντας το μοντέλο UWOT για την προσομοίωση του εξωτερικού υδροσυστήματος της Αθήνας (Πίνακας 1) (βλέπε Κεφάλαιο 8).

Πίνακας 1. Ανάλυση σεναρίων οικιακής ζήτησης σε σχέση με τις χρονοσειρές παροχής νερού

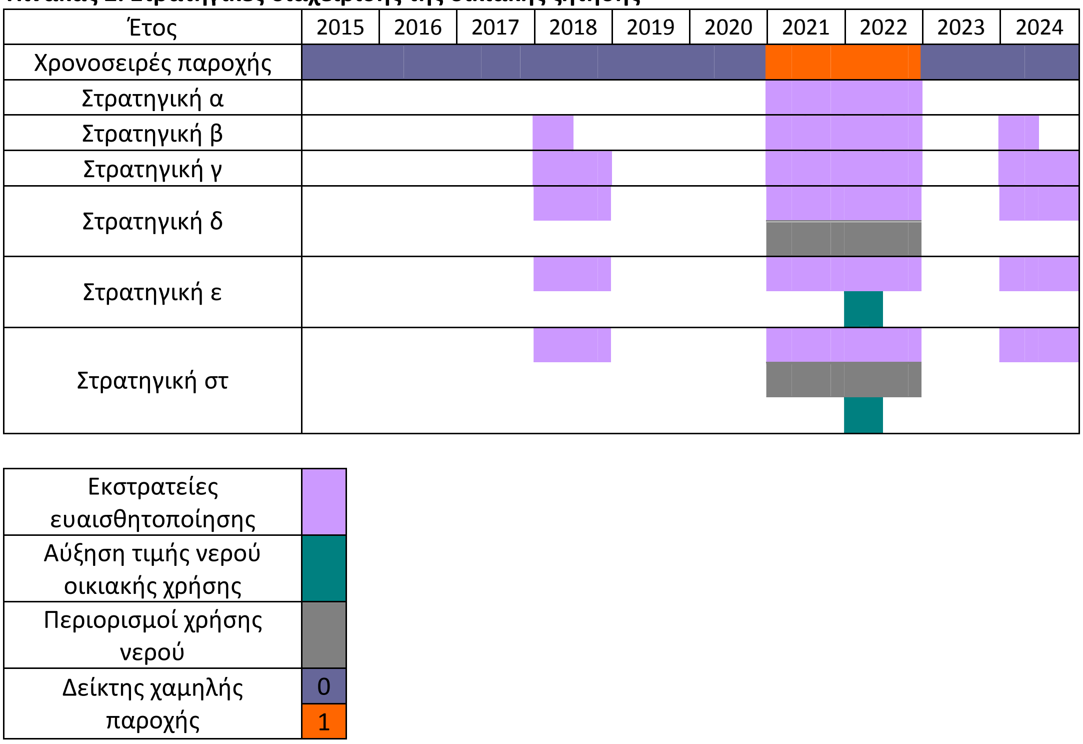
			Χρονοσειρές παροχής									
Σενάρια αστικής ζήτησης	Περιγραφή	Ζήτηση (hm^3)	1	2	3	4	5	6	7	8	9	10
Σενάριο 1	Βασικό	370	√	√	√	√	√	√	√	√	√	√
Σενάριο 2	Αύξηση ζήτησης	450	√	√	√	√	√	√	√	√	√	√
Σενάριο 3	7% αύξηση πληθυσμού	480	√	√	√	+	√	√	√	√	√	√
Σενάριο 4	12% αύξηση πληθυσμού	500	√	√	√	+	√	√	√	√	√	√
Σενάριο 5	20% αύξηση πληθυσμού	550	√	√	√	+	√	√	√	√	√	√

√ αντιπροσωπεύει την ικανοποίηση της ζήτησης
+ αντιπροσωπεύει την μη ικανοποίηση της ζήτησης

Οι συνδυασμοί των σεναρίων ζήτησης και παροχής νερού που οδήγησαν σε αστοχίες στην κάλυψη της ζήτησης επιλέχτηκαν για την ανάπτυξη των στρατηγικών διαχείρισης της ζήτησης νερού (Πίνακας 2).

Επτά πειράματα στρατηγικών διαχείρισης της οικιακής ζήτησης νερού υλοποιήθηκαν με τη χρήση του μοντέλου UWAB. Η προσομοίωση χρησιμοποίησε μηνιαίο χρονικό βήμα, από τον Οκτώβριο 2014 έως και το Σεπτέμβριο 2024.

Πίνακας 2. Στρατηγικές διαχείρισης της οικιακής ζήτησης



Τα αποτελέσματα έδειξαν ότι η προληπτική χρήση των εκστρατειών ευαισθητοποίησης μειώνει αισθητά την πιθανότητα αστοχίας στη κάλυψη της οικιακής ζήτησης νερού από το υδροσύστημα της Αθήνας. Ωστόσο, όπως προκύπτει από την ανάλυση, πιο μακροπρόθεσμες πιέσεις όπως περαιτέρω αύξηση του πληθυσμού σε συνδυασμό με μακριά περίοδο ξηρασίας μπορεί να απαιτήσουν διαφορετικά είδη εφαρμοζόμενων μέτρων όπως για παράδειγμα την επιβολή περιορισμών στη χρήση νερού στους εξωτερικούς χώρους (πότισμα, πλύσιμο αυτοκινήτου κ.ά.).

8. Συζήτηση και συμπεράσματα

Το αστικό σύστημα νερού είναι ένα σύνθετο προσαρμοστικό σύστημα που αποτελείται από όλες τις τεχνικές, περιβαλλοντικές και κοινωνικές συνιστώσες, οι οποίες αλληλεπιδρούν μεταξύ τους μέσα στο χρόνο. Η παρούσα έρευνα επιχειρεί να δημιουργήσει εργαλεία ικανά να εξετάσουν την κοινωνική συνιστώσα και να τα συμπεριλάβει σε μια γενικότερη μεθοδολογία έτσι ώστε να δώσει τη δυνατότητα της προσομοίωσης του πλήρους κοινωνικό-τεχνικού αστικού συστήματος νερού, συμπληρώνοντας τις «υποδομο-κεντρικές» προσεγγίσεις. Σε αυτή την έρευνα:

- Αναπτύχθηκε ένα εργαλείο μοντελοποίησης ευφυών πρακτόρων (UWAB), για την εκτίμηση της οικιακής συμπεριφοράς του νερού υπό διαφορετικές εξωτερικές επιρροές, όπως πολιτικές διαχείρισης της ζήτησης και καιρικές συνθήκες.

- Χρησιμοποιήθηκε ένα υπάρχον εργαλείο για τη διαχείριση του αστικού κύκλου του νερού, το Urban Water Tool Optioneering (UWOT), για να αξιολογήσει την εξέλιξη του αστικού συστήματος νερού υπό τις αλλαγές στην συμπεριφορά της ζήτησης νερού.

- Δημιουργήθηκε μια μεθοδολογία για την ενσωμάτωση του UWAB με το UWOT

- Αξιολογήθηκε η αποτελεσματικότητα και η χρηστικότητα της προτεινόμενης πλατφόρμας μοντελοποίησης διερευνώντας την ικανότητά της να αναδημιουργήσει ένα ιστορικό γεγονός και να αξιολογήσει τις επιπτώσεις διαφορετικών σεναρίων ζήτησης και στρατηγικών διαχείρισης σε ένα αστικό σύστημα νερού

- Η πλατφόρμα μοντελοποίησης UWAB-UWOT αξιολογήθηκε με τη χρήση ενός ιστορικού γεγονότος, την περίοδο ξηρασίας 1988-1994 στην Αθήνα. Η αξιολόγηση βασίστηκε στην ικανότητά της μεθοδολογίας να αναδημιουργήσει την επιρροή των ιστορικών στρατηγικών διαχείρισης της ζήτησης στην πραγματική συμπεριφορά της ζήτησης νερού των αθηναϊκών νοικοκυριών, όπως αυτό καταγράφεται στα στοιχεία της ΕΥΔΑΠ ΑΕ.

- Η πλατφόρμα μοντελοποίησης UWAB-UWOT εφαρμόστηκε στη διερεύνηση της επίδρασης υποθετικών στρατηγικών διαχείρισης της ζήτησης νερού στο αστικό σύστημα νερού της Αθήνας επί διαφορετικών σεναρίων προσφοράς-ζήτησης.

- Η έλλειψη πληροφοριών σχετικά με την συμπεριφορά και τις απόψεις των Αθηναϊκών νοικοκυριών όσο αφορά την κατανάλωση νερού οδήγησε στον σχεδιασμό και στην εφαρμογή δύο κοινωνικών ερευνών με ερωτηματολόγια και μιας κοινωνικής έρευνας με συνεντεύξεις για την επαλήθευση των κανόνων που διέπουν τη συμπεριφορά εξοικονόμησης νερού. Η κοινωνική αυτή μελέτη, αν και δεν είναι νέα μεθοδολογικά, είναι η μοναδική στο είδος για την Αθήνα.

- Τα αποτελέσματα έδειξαν ότι η σύζευξη των δύο μοντέλων είναι επιτυχής και παρέχει σημαντικές νέες δυνατότητες για τον σχεδιασμό και την αξιολόγηση στρατηγικών διαχείρισης της οικιακής ζήτησης νερού από τις εταιρείες ύδρευσης και τους φορείς υδατικής πολιτικής.

Η ουσιαστική συμβολή της παρούσας έρευνας είναι ότι παρουσιάζει μια νέα, εναλλακτική μεθοδολογία για την προσομοίωση της συμπεριφοράς της ζήτησης νερού των αστικών νοικοκυριών, λαμβάνοντας υπόψη τόσο τα τεχνικά (συχνότητα χρήσης των διάφορων συσκευών νερού) όσο και τα κοινωνικά (επιρροές από το κοινωνικό δίκτυο, πολιτικές διαχείρισης κλπ) χαρακτηριστικά της. Πρόκειται για μια σημαντική πρόοδο στην προσπάθεια να συμπεριληφθούν στα εργαλεία διαχείρισης θέματα οικιακής ζήτησης και διαχείρισης αυτής, ενταγμένα στο πλαίσιο ευρύτερων διαχειριστικών και αναπτυξιακών αποφάσεων (σε σχέση πχ με ανάπτυξη υποδομών νερού) ως μέρος μιας μοντελοποίησης του συνολικού συστήματος αστικού νερού.

Ένα επόμενο βήμα της παρούσας έρευνας θα ήταν η χρήση της πλατφόρμας σε μια άλλη μελέτη περίπτωσης η οποία θα επέτρεπε την παραμετροποίηση του μοντέλου με περισσότερα στοιχεία και λιγότερες υποθέσεις. Όσον αφορά το σχεδιασμό του UWAB, αυτό θα μπορούσε μελλοντικά να επεκταθεί με τη δημιουργία διαφορετικών «τύπων» πρακτόρων συμπεριλαμβάνοντας γεωγραφικές πληροφορίες έτσι ώστε να προσφέρουν πιο συγκεκριμένες χρονοσειρές ζήτησης νερού για διαφορετικές εγκαταστάσεις επεξεργασίας πόσιμου νερού μιας πόλης. Τέλος, η δυναμική σύνδεση των εργαλείων UWAB-UWOT καθώς και η ενσωμάτωση δεδομένων από έξυπνες μετρήσεις θα μπορούσαν δυνητικά να παράσχουν καλύτερες εκτιμήσεις για τη συχνότητα της χρήσης των συσκευών συμπεριλαμβανομένων των ετήσιων και των εποχιακών διακυμάνσεων. Τέτοια δεδομένα απαιτούνται για να δημιουργήσουν πιο ρεαλιστικά σενάρια για το μέλλον της ζήτησης νερού και τις στρατηγικές διαχείρισης της ζήτησης.

Η έρευνα αυτή είχε ως αποτέλεσμα αρκετές επιστημονικές δημοσιεύσεις που περιλαμβάνονται στο Παράρτημα VII.

Chapter 1. Introduction

1.1. Context

"Don't let us forget that the causes of human actions are usually immeasurably more complex than our subsequent explanation of them."
Fyodor Dostoevsky

Urban water systems support the majority of the world's population and are influenced by rapid urbanisation, climatic changes and inadequate provision of public services that often cause problems in water availability, sewerage management and wastewater treatment (Global Water Partnership, 2012). The allocation and management of water resources is influenced by political and economic decisions of all the interlinking sectors of the food–energy–health–environment 'nexus' (WWAP, 2012). Decision makers in the water resources management domain have to deal with a wide range of issues, from simple water quality problems, to complicated ones, such as creating strategies to address, in the long run, increasing water demand. Rising water demands and increasing supply uncertainty puts pressure on governments, water utilities and the public to acknowledge the need for water conservation in order to avoid future water shortages and environmental problems (Inman and Jeffrey, 2006).

To tackle this issue of managing both supply and demand, more integrated, system-level approaches to the urban water cycle through a unified urban cycle management framework, have recently been emerging in literature (including for example Rozos and Makropoulos 2013; Behzadian et al., 2014; Bach et al., 2014), but even these, leave the water end-user essentially out of the simulation domain. However, the continuous variation, of weather conditions, increases the uncertainty regarding the available water volume, while the changing socio-economic conditions (economic conditions, changing population, tourist arrivals etc.) increase the uncertainty regarding water requirements.

This uncertainty is further increased, when trying to anticipate the reaction of the public to different water demand management policies, not to mention, to strategies that include more than one measures in different times and for different periods. Water end users are people that usually believe that water is an abundant public resource, since it is everywhere and it is cheap. They tend to disconnect the water running from their tap from the water stored in an aquifer. They also tend to attribute a hedonistic dimension to water and to its overuse as a link to a higher quality of life, with a strong value of cleanliness and hygiene and a lifestyle that uses water for pleasure. These attributions to water, result in even more difficulty to foresee the effects of different water demand management strategies to water demand behaviour (Koutiva et al., 2015).

Additionally, two of the main challenges in embedding the water end-user into the urban water cycle are (a) the estimation of the water demand related behaviour of households and (b) the quantification of the way in which this behaviour is affected by water demand management measures such as awareness raising campaigns and water price changes. These water demand management measures affect in turn the formation of people's attitudes which eventually form behaviours (Koutiva and Makropoulos, 2015).

It is therefore necessary to find tools that facilitate the understanding of the dynamics of human group processes which are "complex, nonlinear, path dependent and self-organizing" (Macy and Willer, 2001). For this reason, adaptive urban water management requires tools able to model the socio-economic aspects of the water system, on top of those already used to support water resources management, able to demonstrate self-organization and adaptation and present heterogeneity across both spatial and temporal scales (Pahl-Wostl, 2007a).

Furthermore, a basic premise of adaptive urban water management is that of learning. As such the ability to use models as "experiments" whose learning outcomes inform decision makers on the effects of strategies on the water system is sine qua non. Thus it is essential to be able to model water demand behaviour explicitly and link it to the hydrosystem's response, rather than simply replicate historical water demand evolution.

Within this context, Agent Based Modelling (ABM) has been identified as a tool that captures emerging (bottom-up) behaviour and is capable to simulate the dynamic interaction between socio-economic, natural and technical components thus providing a modelling tool for exploring diverse water management decisions and strategies (including for example water demand management: Koutiva and Makropoulos, 2011; flood management: Wheater et al., 2007 and catchment management: Barthel et al. 2008). ABM is a contemporary computational intelligence tool that is capable to address complex system characteristics of coupled socio-environmental systems (Filatova et al. 2013) providing the missing link for supporting truly adaptive urban water management (Wheater et al., 2007, Koutiva and Makropoulos, 2011).

This research focuses on developing methods and tools able to evaluate the change of domestic water demand behaviour under different external forces such as policies and climate conditions and assess the urban water system's reaction. The following paragraphs present the research aim, questions and objectives, the research methodology as well as the main innovations of the research undertaken.

1.2. Research aim and objectives

The main aim of this research is to create a methodology and associated model to formally include the domestic end users of the urban water system within an integrated, adaptive water management framework, able to assess the effect of alternative water demand management strategies on the reliability of water service provision.

The aim of this research was achieved following a predefined set of four research objectives that are complemented by research questions, acting as a roadmap for this work. The overall methodology is presented in Figure 1-1 and is summarised as follows:

A. Develop a solid theoretical basis analysing the theoretical aspects of the research and to create a theoretical basis for adaptive urban water management. The main research question is:

"Which theories are required to create a methodology that could be used to evaluate the domestic water demand behaviour and support adaptive urban water management?"

As presented in Figure 1-1, the theoretical background is divided into three basic theoretical dimensions: the description of the urban water system focusing on the management of the domestic water demand, the urban water system's categorisation as a complex adaptive system and the use of social psychology theories to identify and evaluate the driving mechanisms behind urban water demand.

B. Develop new tools and methods by identifying appropriate and develop novel tools that are capable of addressing the social, natural and technical dimensions of the urban water system. The main research question is:

"**Which are the most applicable methods and relevant tools that will support adaptive urban water management?"**

As presented in Figure 1-1, three methods and tools were identified: social research methods for extracting information from the public regarding water demand behaviour, Agent Based Modelling as a means to model the evolution of water demand behaviour of urban households and the Urban Water Optioneering Tool as a means to "translate" the domestic water demand behaviour into actual volumes of water requested from the urban water system.

C. Propose an integrated modelling methodology by designing and developing a modelling platform that would enable decision makers to experiment with, monitor and learn from the outcomes of the long-term effectiveness and impact of decisions on the urban water system and thus create strategies for water demand management as part of integrated water resources management. The main research question is:

"**How to combine different tools and methods in order to create one consistent modelling platform that will be able to support decision makers?"**

As presented in Figure 1-1, the modelling methodology includes those parameters, rules and methodological steps that are required in order to be able to simulate the evolution of domestic water demand behaviour under different external forces and to translate this evolution into actual water demand volumes. Specific computational environments were employed (UWOT, NetLogo, Matlab, JavaVM) to develop the modelling platform as a proof of concept.

D. Apply, validate and test by selecting a case study for applying the developed modelling platform both in historical mode (calibration and validation) and scenario mode (forecast, learning). The main research question:

"What is the effectiveness and usability of the developed modelling platform?"

As depicted in Figure 1-1, the created modelling platform was applied to the Athens urban water system to test its validity and usability. The validity of the modelling platform was tested using a historical drought event between 1988-1994 while the usability was tested by experimenting with the effect of different water demand management strategies to the water demand and supply scenarios of the Athens urban water system.

Figure 1-1 Overall research methodology

1.3. State of the art

The research undertaken is of an interdisciplinary nature, combining theories and tools from different disciplines, including physics, social science, engineering and information technology, to create a methodological approach and a modelling platform that takes into consideration the urban household's behaviour in estimating domestic urban water demand. The main theoretical building blocks of this research are:

a. **Evidence base on water demand shaping factors** where several domestic water end use studies have identified that household water demand is affected by numerous socio-demographic, cultural, psychological and social factors, among which the residents' environmental awareness, perceptions on water consumption, cognitions and beliefs on the value of water, trust on authorities and government (Arbués et al, 2003, Barrett, 2004, Kenney et al., 2008, Campbell et al, 2004, Gilg and Barr, 2006, Gregory and Di Leo, 2003, Randolph and Troy, 2008, Harlan et al, 2009, Hurlimann et al, 2009, Jorgensen et al, 2009, Fontdecaba et al, 2012, Beal et al, 2011a and b, Willis et al, 2011, Mondejar-Jimenez et al, 2011, Jones et al, 2011).

b. **Theories on adaptive urban water management** that illustrate the importance of the combination of Integrated Urban Water Management tools with an adaptive management approach integrating all the dimensions of urban water cycle under one overarching management regime (Magnuszewski et al., 2005,Pahl-Wostl et al., 2007, Keath and Brown, 2009, Pearson et al., 2010, Brown et al., 2011, de Graaf et al., 2011).

c. **Strategies of water demand management** of both price, such as domestic water price increase, and non-price, such as awareness raising campaigns and restrictions, that aim at decreasing water demand by changing the water demand behaviour of urban households (Howarth and Butler, 2004, Butler and Memon, 2006, Gaudin, 2006, Inman and Jeffrey, 2006, Mitchell, 2006, Brown and Farrell, 2009, Beal et al., 2011a, Kampragou et al., 2011).

The above theoretical foundations of domestic water demand formation and management, were operationalised utilising the unique properties of Agent Based Modelling, that is capable to capture complex system characteristics of coupled socio-environmental systems (Filatova et al., 2013), for modelling the complex adaptive nature of the urban water system (Van Dam et al., 2013, Nilsson and Darley, 2006, Borshchev and Filippov, 2004, Tesfatsion, 2003, Railsback, 2001).

In this research, an Agent Based Model was created that integrates two different theories of social psychology and couples them with complex network theory, in order to represent the links between the domestic water users of a city, as it was suggested by Sobkowizc (2009) and has been used also for simulating the social network of domestic water users for example, in Galan et al., 2009. These theories are:

a. The **Social Impact Theory** (Latane, 1981) that was used to address the effects of society, policies and other external forces to the domestic water users' behaviour, in correlation with the promotion of pro-environmental behaviour (Aoyagi et al., 2012) and the effect on common pool resources of social norms (Brucks et al., 2007). Social Impact Theory has been combined with cellular automata (Latane, 1996, Nowak and Lewenstein, 1996) and agent based models (Holyst et al., 2000, Kacperski and Holyst, 2000) and complex network theory (Aleksiejuk et al., 2002, Sobkowizc, 2003a and 2003b).

b. The **Theory of Planned Behaviour** (Ajzen, 1991) that was used to deconstruct the domestic water user's behaviour into components for modelling behavioural intention. As Hurlimann et al. (2009) reported, the Theory of Planned Behaviour may be used in evaluating the drivers of water demand (Jorgensen et al., 2009, Fielding et al., 2010). Additionally, the Theory of Planned Behaviour and agent based modelling have been combined, in the past, for analysing domestic water demand habits and behaviours (Schwarz and Ernst, 2007, Linkola et al., 2013).

The above theories were incorporated with statistical mechanics to deal with the inherently stochastic nature of human behaviour and include stochasticity in the created Agent Based Model's behaviour. Statistical mechanics have been previously used to capture the main features of a given social phenomenon (Castellano et al., 2009).

Additionally, social research methods, of both qualitative and quantitative nature, were employed to understand behavioural and attitudinal concepts of domestic urban water demand. This approach is rather common (Dunlap et al., 2000, Gilg and Barr, 2006, Wisker, 2007, Russell and Fielding, 2010, Dolnicar et al., 2011, Browne et al., 2013), nevertheless this is the first time that the water demand attitude and behaviour of Athenian households have been assessed in such a concise and thorough approach (Koutiva et al., 2015, Gerakopoulou and Makropoulos, 2013).

Finally, an existing urban water management model, the Urban Water Optioneering Tool (UWOT) was linked with the created Agent Based Model to simulate the evolution of domestic water demand and the response of the hydrosystem. This tool has been used in the past for simulating the Athens urban water system (Rozos and Makropoulos, 2012, Baki and Makropoulos, 2014) which constitutes it, a good modelling choice for the selected case study.

1.4. Innovation

"If we knew what it was we were doing, it would not be called research, would it?"
Albert Einstein

The combination of the above building blocks into one methodology and modelling platform for the simulation of the complete "socio-technical" urban water system is one of the main innovations of this research. In this work, these building blocks and theories have been used in a much more integrated fashion than ever before and have produced the following key innovations:

Modelling platform:

- Although past approaches on water demand behaviour simulation using agent based modelling recreate a hydrological model within the agent environment such as that of Becu et al. (2003) and Barthel et al. (2008), in this research, two tools were combined, an existing one for assessing the technical and physical component of the urban hydrosystem and a newly developed one for modelling the water demand behaviour of urban households. Contrary to the beaten track, this new approach enables the use of already pre-existing data-processing tools for hydrological and technical modelling and combines them with a new modelling tool for addressing the social component. This possibility allows the user to investigate the behavioural change of the domestic water user, that up until now remained a black box due to the many shaping factors of water demand behaviour, allowing a much more thorough, and thus better, assessment of the urban water system's response to alternative water demand management strategies.

- A well-known problem and challenge in agent based models, which are meant to be exploratory is the need to make assumptions. To balance this we developed and propose to use sensitivity analysis, uncertainty analysis and calibration methods for selecting reasonable - informed - parameters in the hope that this approach will provide a more transparent way for setting up such models.

Agents' behavioural rules:

- The agents' behaviour is developed integrating three social psychology theories for the first time in this particular way. The complex network theory is used to define the urban household's social network. The Social Impact Theory is used to estimate the social influence that is exerted to every urban household regarding water conservation attitude. Finally, the Theory of Planned Behaviour is used to create a behavioural rule that is able to translate the water conservation attitude of the urban household to an actual water saving behaviour of three different levels. The final decision of the agent is selected by utilising statistical mechanics concepts to incorporate the stochastic nature of human behaviour. This is a unique feature of this work, taking advantage of all three theories and integrating them with statistical mechanics concepts. This feature goes beyond similar work such as Galan et al., 2009, that uses an opinion diffusion model or Yuan et al., 2014, and Athanasiadis et al., 2005 that focus mainly on the effects of water price changes using water price and household income elasticities.

- The agent based model's user identifies the mean values of all of the UWAB's descriptive parameters that characterise the urban society under investigation. UWAB distributes normally, the selected mean of every parameter, to the household agent population assuming that the normal distribution is descriptive of the respective conditions. This method was used for all parameters in order to create heterogeneity in the micro-level that results in a macro-level description as close as possible to the real society under investigation. This is a novel approach in terms of agent based models for water demand behaviour, which helps to define the social conditions in place but increases the uncertainty of the model's behaviour as well.

- This research approaches water price changes in a novel manner, drawing conclusions from both theory and the selected case study and applying them in the proposed methodology. In particular, the agents' water conservation attitude is affected by the transmitted information regarding price changes and the water demand behaviour from the effects of past saving behaviours to the household's water bill. This is a new approach, focusing on the information about water price changes and not the actual change, contrary to either the use of econometric functions for translating water price changes to water demand (Athanasiadis et al., 2004) or the exclusion of water prices changes from behavioural rules (Galan et al., 2009) because water price is inelastic (Arbues et al., 2004).

- All of the agents' rules use statistical mechanics for incorporating stochasticity. This constitutes a novel use of statistical mechanics and at the same time provides a robust methodological framework for capturing the uncertainty that governs human behaviour (Macy and Willer, 2002).

- The behavioural rules were created by combining heuristic methods, the Theory of Planned Behaviour and the results of a qualitative social study (interviews with a sample of water users). This link between literature, theory and field surveys is novel and has not been reported before in the literature.

Data:

- Although case specific agent based models do exist that have been created to simulate the water system of a specific area such as the models created by Schluter and Pahl-Wostl (2007) and Janmaat and Anputhas (2010), in this research we develop a new general modelling platform that can be used both for historical event analysis and scenarios testing.

- Data regarding social behaviour are both difficult to acquire and case specific. Two quantitative social research studies (an internet survey and a phone survey) and a qualitative social research study were created to extract information regarding water demand attitudes and behaviours. The data collected and the findings of the surveys are novel in their own right and provide an evidence base for the development of this research which does not often exist in similar studies. The social research studies were focused on Athenian households and this is the first time that the water demand attitude and behaviour of Athenians has been extensively explored (Koutiva et al., 2015 and Koutiva and Makropoulos, 2015a).

- To address the well known problem of the difficulty of collecting data to setup social simulation models, in this research, we developed a novel method based on (a) using data that are easily available, such as social characteristics from national censorial data and (b) defining other more difficult model parameters through multi-objective evolutionary calibration. This approach is both robust and novel and is a key feature of the methodological proposition.

Decision Support

- The proposed method and tools is the first modelling framework that includes all the components of urban water management in the same model, including an explicit representation of domestic end users. This innovation allows decision makers to explore new types of scenarios for water management and investigate trade-offs between engineering and soft interventions in a way not possible before.

- One of the main key conclusions from the implementation of the modelling platform to water demand and supply scenarios and different demand management strategies is that the precautionary use of awareness raising campaigns decreases the unmet volume of water demand and that the duration of the campaign is an important factor influencing the level of this decrease. It is suggested that water companies can use UWAB to calculate the duration of such campaigns and associate it with drought indicators as means to initiate timely water demand management measures.

1.5. Structure of Thesis

This PhD thesis is organised into nine chapters:

Chapter 1 introduces the research context, its aim and presents the research methodology and the key innovation aspects.

Chapter 2 presents the theoretical background needed for this research. More specifically, this chapter discusses adaptive urban water management, water demand management policies, shaping factors of water demand behaviour, introduces the key elements of complex adaptive systems and statistical mechanics and theories relevant to social psychology including complex networks theory, Social Impact Theory and the Theory of Planned Behaviour.

Chapter 3 reviews the methods and the tools that are used in this research. Social research methods are briefly presented. Computational intelligence methods are briefly presented, and compared and agent based modelling is identified as a promising tool for the simulation of domestic water demand behaviour. In addition, the Urban Water Optioneering Tool (UWOT) is presented and its ability for simulating the evolution of domestic water demand is discussed.

Chapter 4 presents the methodology that was followed to create the agent based model Urban Water Agent Behaviour (UWAB) that simulates domestic water demand behaviour. In addition, the Chapter presents the methodology for using UWOT for simulating the evolution of domestic water demand. Finally, it describes the proposed methodology for linking the two models leading to the creation of the UWAB-UWOT modelling platform.

Chapter 5 presents the actual development of the UWAB model using the NetLogo agent based modelling platform, the use of UWOT and the use of Matlab and JavaVM for linking these two modelling tools.

Chapter 6 presents the Athens urban water system that was selected to test the validity and the usability of the developed modelling platform. The chapter presents the implementation of social research methods for extracting information regarding water use attitudes and behaviours. Finally, this chapter presents the data required for setting up the UWAB-UWOT model for Athens.

Chapter 7 presents the implementation of the UWAB-UWOT modelling platform to the selected case study of the Athens drought period of 1988-1994 including, the sensitivity analysis and the calibration process of UWAB's experimental parameters.

Chapter 8 presents the use of the calibrated UWAB-UWOT modelling platform to scenarios of water demand, investigating different water demand management strategies.

Chapter 9 discusses the usability of the research, the innovation of the created modelling framework and proposes further research.

Chapter 2. Theoretical Background

2.1. Introduction

Domestic water demand behaviour is closely intertwined with the user's mental representation of water as a "nature's good", the existential 'pleasure of water', the positive self-image of the people with high environmental consciousness social identity, the level of trust towards the political water control and the cognition errors related to water availability (Koutiva et al., 2015). Additionally, domestic water demand behaviour is the shaping factor of domestic water consumption that is one of the main pressures to the urban water system driving changes and creating impacts to the system's natural and technical components.

To understand the processes relevant to domestic water demand, both autonomous and interconnected and their effects to the urban water system, it is necessary to integrate aspects from many disciplines. Firstly, it is suggested to analyse the specifics of the urban water system focusing on the shaping factors of domestic water demand and the respective management approaches. Human – environment interactions are difficult to be analysed if only the attitudes and behaviours of individuals are assessed (Kurz, 2002). Thus, it is important to understand the social organisation of demand since people's behaviour is shaped not only by their individual characteristics but also by the housing market, fashion, entertainment and lifestyle (Harlan et al, 2009). Understanding environmental commitment of individuals and society requires a deeper appreciation of beliefs that can be explored by adopting a social practices approach (Barr et al, 2011). For that reason this research suggests to use theories relevant to social psychology in order to explore the shaping mechanisms of water demand attitudes, their transformation to behaviours and the influencing role of society.

This chapter presents the theoretical background that was used in this research focusing on the domestic water demand component of the urban water cycle and on water demand management policies. Additionally, the chapter presents complex adaptive systems' theory and the use of statistical mechanics. Finally, this chapter presents three theories relevant to social psychology regarding human attitude and behaviour formation, the complex network theory, the Social Impact Theory, and the Theory of Planned Behaviour accordingly. Figure 2-1 presents a schematic representation of the chapter's contents.

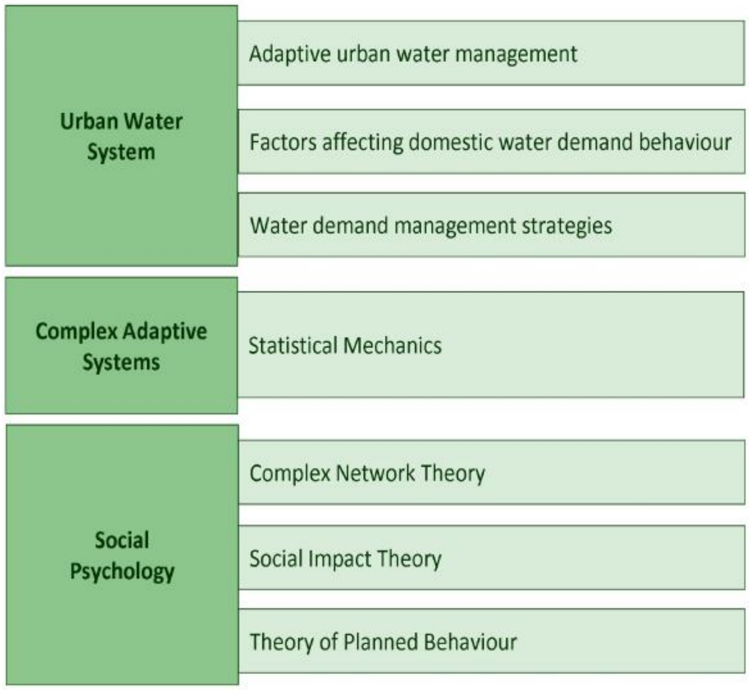


Figure 2-1 Schematic representation of the theoretical background

2.2. Urban Water System

The urban water system consists of three components, the natural (water resources), the technical (water infrastructure) and the social (water users) that are autonomous, following their own complex processes, interconnected, linking with each other, and evolve in time (House-Peters and Chang, 2011).

Urban water systems are increasingly pressurised by climatic conditions, population change, resource limitations and ageing infrastructure (Ferguson et al., 2011). Even though globally freshwater resources are not yet scarce, their unequal distribution at even at different social groups within a river basin may be a source of tension (Pahl-Wostl et al., 2010).

The following paragraphs analyse the concept of adaptive urban water management, discuss the shaping factors of domestic water demand behaviour and finally present available water demand management policy options.

2.2.1. Adaptive urban water management

"Water governance refers to the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" (Global Water Partnership, 2002).

More water resources management issues have been associated with governance failures than with the failures of the resource itself (Rogers and Hall, 2003). It is anticipated that these water management challenges will be exacerbated in the future as climate and socioeconomic conditions change (Bates et al., 2008). Therefore, the launch of coordinated actions from the European Community in order to strengthen the policy initiatives aiming at combating the impacts of climate change to water resources (Mimikou and Baltas, 2013). The European Water Framework Directive (WFD) (2000/60/EC), through the coordination of all strategies and policies relevant to water, supports the Integrated Water Resources Management (IWRM). The WFD introduces several innovations in water management, which are (based on Page and Kaika, 2003):

i. Co-ordination of policies that previously addressed different water types separately, and co-ordination of water management strategies

ii. Switching to river management based on hydrological boundaries, not political administrative and national boundaries

iii. Introducing the 'combined approach' to pollution control by linking emission limit values to environmental quality standards

iv. Redefinition of 'good water status' and redrawing of the list of priority hazardous substances

v. Increasing public participation in policy-making in order to increase transparency and compliance

IWRM is "a process which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000).

Even so, there is a growing criticism of IWRM suggesting that it may be inapplicable (Pahl-Wostl et al., 2007b) and ultimately unable to really support decision making (Biswas, 2004). However, researchers recognise IWRM's strength in providing a good theoretical basis for identifying the major water management issues and their conflicting interests (Pahl-Wostl et al., 2007; Butterworth et al., 2010). To assist IWRM to progress to the next level, it has been proposed that IWRM can be upgraded by recognising uncertainty (Gregory et al., 2006), by taking into account learning outcomes, the human dimension (Pahl-Wöstl and Sendzimir, 2005, Pahl-Wostl, 2009, Gleick, 2003, Pahl-Wostl et al., 2010) and by exercising a more practical, adaptive management model (Lankford et al., 2007). In addition, the cyclical review management process, proposed by the European Water Framework Directive (2000/60/EC), is arguably consistent with the notion of adaptive management (EC, 2009).

Adaptive management is a natural resources management approach that can be traced back to 1978 in B. Holling's publication on "Adaptive Environmental Assessment and Management" (Holling, 1978) where he defined adaptive resources management as a method for implementing policies as experiments. Adaptive resources management was further elaborated in 1986 by C.J. Walters in his book "Adaptive Management of Renewable

Resources" were he outlined that adaptive "management involves a continual learning process that cannot conveniently be separated into functions like research (and ongoing regulatory activities), and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity." Furthermore in 1993 K.N. Lee in his book "Compass and Gyroscope: Integrating Science and Politics for the Environment" noted that "managing large ecosystems should rely not merely on science, but on civic science; it should be irreducibly public in the way responsibilities are exercised, intrinsically technical, and open to learning from errors and profiting from successes."

A more recent review undertaken by the United States Department of Agriculture in 2005 concluded that adaptive management is a systematic "learn by doing" method that proposes feedback loops, based on learning outcomes, that change management approaches accordingly (Stankey et al., 2005).

Adaptive management shifts linear decision making processes (crisis - analysis - policy) to cyclic integrating modifications on assessment, policy formulation and implementation, and monitoring to track and manage changes (Figure 2-2).

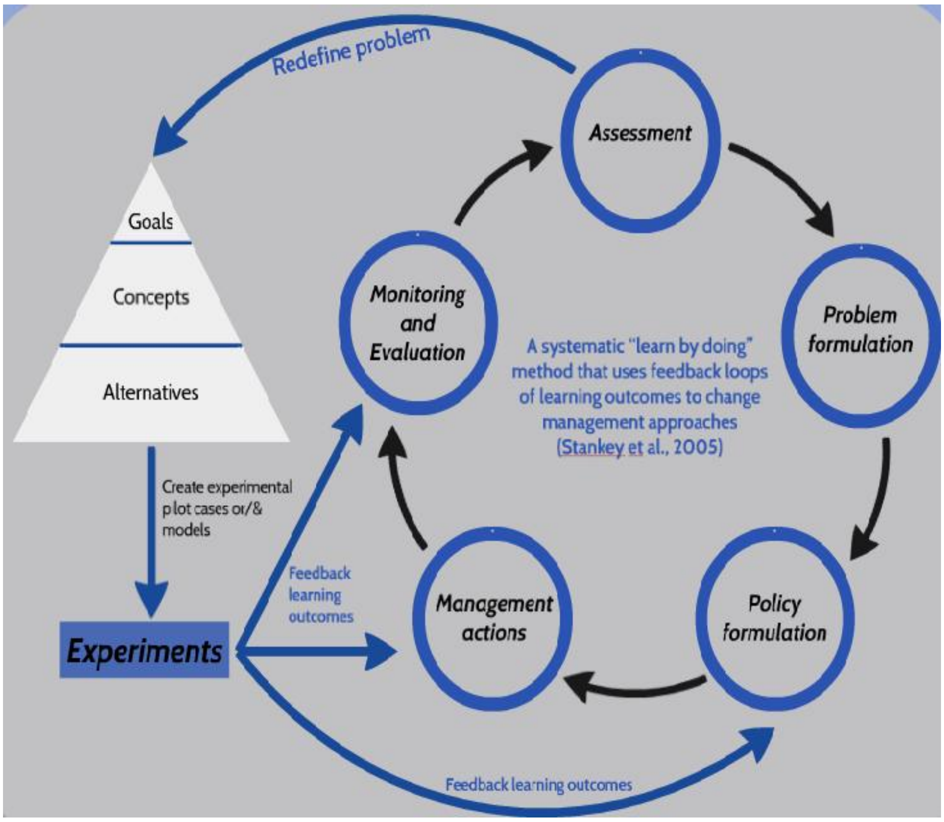


Figure 2-2 Cyclic adaptive management process

However, how can water managers decide what measures they should apply and how can they adapt their decisions to the changing urban water system? In the majority of the EU member states, water managers follow legislative instruments and their current approaches often are "trial and error" implementations that require new decisions every time a review point is reached and without a formalised plan for learning from current decisions (Convertino et al., 2013).

Jeffrey and Gearey (2006) suggest that adaptive management acknowledges that surprises are inevitable and thus uncertainty regarding the quality and availability of water resources is a fundamental notion of the water system requiring the constant adaptation of society by generating and exploiting all available options for change. Therefore, they have concluded that the water sector needs to move towards using modelling tools for development water management processes.

Additionally, Integrated Urban Water Management (IUWM) seeks to manage the urban water cycle as a whole, changing the impact of urban development on the natural water cycle, promoting a more efficient use of resources that can be achieved providing economic benefits and improved social and environmental outcomes (Barton and Argue, 2009). Furthermore, Pearson et al. (2010) identified that IUWM is the operational approach of urban water management while adaptive resources management is the strategic one, with IUWM being used for creating tools, integrating social issues as well, to understand and analyse the urban water system. In addition, Keath and Brown (2009) identified that an adaptive, integrative management of the total urban water cycle is able to secure resilience to future uncertainties arising from both climatic, infrastructure and social changes, thus increasing cities' liveability.

Nevertheless, the main obstacles to the implementation of an adaptive and integrated urban water management remain in changing institutional practices of urban water management were the lack of experience, resources both in terms of funds and manpower and information in the form of guidelines, standards and documentation for design, construction, maintenance, monitoring and evaluation (Rijke et al., 2012). In addition, even though IUWM recognises social and political dimensions of the urban water system the majority of IUWM projects deal mainly with the technical, infrastructure dimension of the urban water system trying to implement total water cycle integration by considering collectively water supply, storm water, wastewater, and ground water (Mitchell, 2006).

To conclude, adaptive urban water management is a term that has been used to signify the combination of IUWM tools with an adaptive management approach and the integration of all the dimensions of urban water cycle under one overarching management regime (Keath and Brown, 2009, Pearson et al., 2010, Brown et al., 2011, de Graaf et al., 2011).

This is where the notion of experiments within the learning, adaptive approach to water resources management emerges (Zhou et al., 2013). For example, Figure 2-3 presents two scenarios of water demand management and their use of social learning while operating. The difference, between these scenarios is that the adaptive urban water management scenario (Scenario B) evolves by incorporating social learning as time passes implementing different measures (D2 – D3 – D4) that change urban water management through the integration of systems thinking, while the non adaptive urban water management scenario

(Scenario A) remains in a prestructural mode, addressing each issue individually (D1 – D5 – D6 - Dn) without making use of learning outcomes from previously implemented measures.

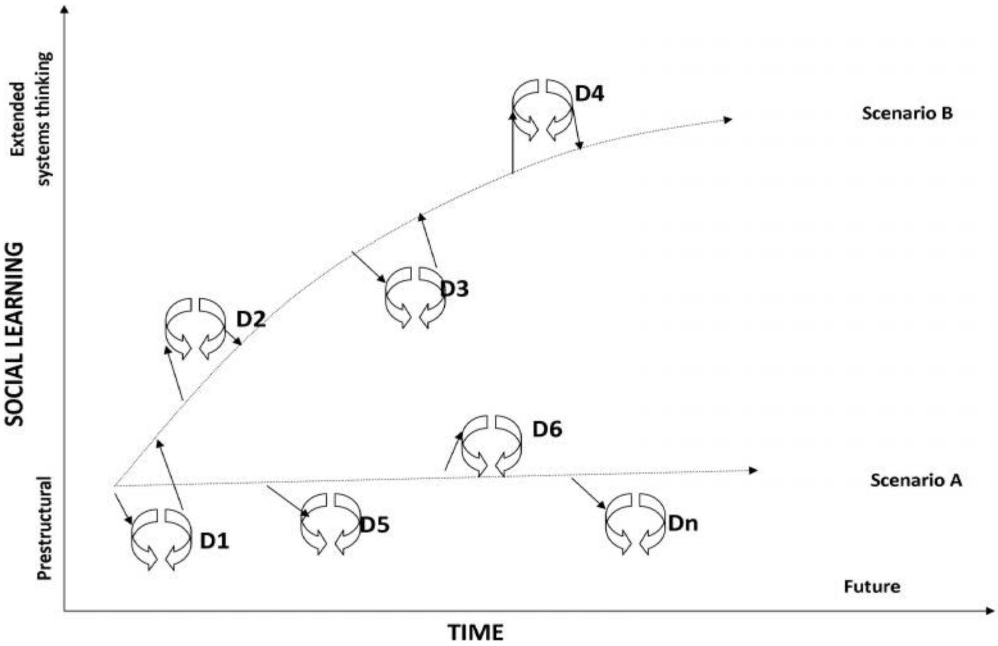


Figure 2-3. Water demand management scenarios that include (scenario B) or not (scenario A) social learning feedback (Pearson et al., 2010)

Following from this realisation, in this research, adaptive urban water management is used to create a methodology aiming at assessing the effects of the human dimension to the urban water system. Specifically we propose to develop a computational tool to assess the effectiveness of water demand management strategies. These strategies will be created as experiments to allow a "social learning" feedback into the water demand management practitioners as proposed by adaptive urban water management. The hypothesis is that this will allow them to make informed decisions, selecting the water demand management strategies depending on the urban water system's response, modelled by the modelling platform created in this research and presented in Chapter 4.

To develop this tool, we need to better understand the determinants (or shaping factors) of domestic water demand and look into how relevant water demand management policies can affect them. This is discussed in the following sections.

2.2.2. Shaping factors of domestic water demand

A household's water using behaviour results in the actual water volume that every urban household demands from the urban water system. This volume is linked to the water requirements and the frequency of use of every water appliance. In 2001, EU Member states reported a mean water use in litres per person per day from 90 to 280 l/p/d (EUROSTAT, 2012). This is well above the basic water requirements as they were identified by Gleick, in 1996. Gleick (1996) proposed the establishment of a guaranteed basic water requirement standard of 50 litres per person per day (Table 2-1) to cover all the basic needs for drinking, sanitation, bathing and cooking. Furthermore WHO's basic water consumption is defined at around 40 and 70 litres per person per day (L/p/d) and covers personal drinking, sanitation and some additional activities such as house cleaning and waste disposal (Howard and Bartram, 2003).

Table 2-1 Recommended water requirements for human needs (Gleick, 1996)

Purpose	Recommended minimum (litres per person per day)	Range (litres per person per day)
Drinking Water[a]	5	2 to 5
Sanitation Services[b]	20	0 to over 75
Bathing	15	5 to 70c
Cooking and Kitchen	10	10 to 50c
Total	50	

[a] True minimum to sustain life in moderate climatic conditions and with average activity levels.

[b] A mean (not minimum) of 40 litres per person per day is considered adequate for sanitation purposes in industrialised countries.

[c] Upper values represent societal preferences in industrialised countries.

However, this increased water demand of EU households may be attributed to the increased quality of living conditions that allow a hedonistic use of water (Koutiva et al., 2015). This notion is supported by the fact that household water uses may be divided into two separate categories: those for covering everyday basic needs (or non-discretional) and those for covering discretional uses (Willis et al. 2011). Basic needs include water uses related to drinking water, sanitation (flushing toilets), bathing (using the hand basin, shower, bath, washing machine) and kitchen activities (kitchen sink and the dishwasher). Discretionary needs cover additional non-essential water uses, such as irrigation and outdoor activities. Nevertheless, the shift towards non-materialistic needs (Inglehart, 2008) has made many basic water needs to include a large discretionary component, such as showering or bathing for relaxing and not for sanitation purposes (Willis et al., 2011).

A baseline water demand of a household refers to the intrinsic motivation and self-determination in the behaviour of the household. Intrinsically motivated and self-determined behaviours are those that "represent the prototypes of self-determined or autonomous activities … that people do naturally and spontaneously when they feel free to follow their inner interests." (Deci and Ryan, 2000) In other words, this baseline water demand of the household represents a water use "intrinsic tendency" before being influenced by water demand management policies, its social network, or the weather. This assumption is backed up by a significant evidence base suggesting that people's basic values are in their majority set by the time they reach adulthood, and change relatively little thereafter (Rokeach, 1968, Inglehart, 1977, 1997, 2008). Therefore, domestic water demand management is necessary to aim at informing and educating the public for achieving a shift of water demand behaviour towards water conservation.

Several domestic water end user studies have identified that household water demand is affected by several social and psychological factors, including: residents' age, income level, household occupancy, education level, housing characteristics (size, age, type of water consuming appliances) and other factors relevant to the residents' environmental awareness, perceptions on water, trust on authorities and government and innovation level (Arbués et al, 2003, Barrett, 2004, Kenney et al., 2008, Campbell et al, 2004, Gregory and Di Leo, 2003, Randolph and Troy, 2008, Harlan et al, 2009, Hurlimann et al, 2009, Jorgensen et al, 2009, Fontdecaba et al, 2012, Beal et al, 2011a and b, Willis et al, 2011, Mondejar-Jimenez et al, 2011, Jones et al, 2011).

The following paragraphs present research findings regarding the shaping factors of domestic water demand. These factors are summarised in Table 2-1.

Jorgensen et al. (2009) conducted a literature review of several social models and concluded that water consumption is influenced directly by climate and seasonal factors, demographics, dwelling characteristics, household composition, past water use behaviour and perceived behavioural control and indirectly by the user's conservation intention which is influenced by the user's own attitudes towards conservation, habits, restrictions and prices and by the user's own perceptions of trust, outdoor interest and risk of water shortage (Jorgensen et al., 2009).

Randolph and Troy (2008) explored the impact of the socio-economic, attitudinal, and behavioural factors on urban water demand in Sydney, Australia. They identified that family houses consume more water than denser buildings, such as flats, mainly because of their size. Their findings pinpointed that homeowners have direct control over their water related fittings, technologies and appliances. In addition, flat residents, the majority of which are usually tenants, have usually no saying in the water related equipment and fitting of the building, they live in. Furthermore, property owners and developers have little interest in equipping their houses with water conservation technologies. Their research concluded that since population living in flats is projected to increase it is important to target these households as well as property owners and developers in water conservation campaigns.

Harlan et al. (2009) studied the effect of income and overall affluence in water consumption in an arid city, Phoenix (USA). They concluded that household income is a parameter affecting household water consumption and is indirectly related mainly to house size, probably associated with the number and size of water-intensive possessions, and outdoor characteristics, associated with the possession of a swimming pool and a large landscaped garden. Finally, they proposed that water conservation policies should target mainly property developers, rather than homeowners, for promoting water saving.

Fontdecaba et al. (2012) studied domestic water consumption in different socioeconomic groups in Barcelona, Spain. They identified a positive correlation between income level, education level, and large house size and water consumption. Finally, their conclusions proved the existence of a relation between socioeconomic parameters, water consumption, and the possibility to use socioeconomic groups to address more effectively water consumption by employing different water conservation policies.

Mondejar-Jimenez et al. (2011) identified that income level, education level, house type, and professional situation of Spanish households affect water consumption levels. Their findings concluded that environmental awareness increases water conservation attitudes thus decreasing water consumption, while lifestyle is inversely correlated with water conservation attitudes, meaning that an increased income level and education level does not necessarily lead to an increased water conservation attitude.

Kenney et al. (2008) studied factors influencing water demand during a five-year drought period in Colorado, USA. They identified that consumption use is affected by weather conditions, water prices, water restrictions, and social characteristics. They identified that high consumption was related to higher income, age, and newer and larger houses. They have concluded that water utilities need to recognize the necessity to use customer-specific water budgets for managing water demand and thus water revenues.

Willis et al (2011) conducted a study in Australian households using both metering of water components and questionnaire survey and identified common demographic characteristics of water consumption groups (low and high). The lower consumers consisted more of families rather than singles and couples and income level and house size was not statistically significant. Their research concluded that environmental and water demand attitudes have the most important role in water conservation.

Beal et al (2011 a and b) conducted a baseline end use analysis on domestic water consumption in households in South East Queensland, Australia. This analysis employed high-resolution water meters, remote data transfer loggers, household water appliance audits and a self-reported household water use diary. Their main findings were that households that identified themselves as high water users consumed less water than those identifying themselves as low or medium water users. In addition, they indicated that younger households consumed less water and that the high consumers were in general older, with lower income and living in smaller households.

Table 2-1 summarises the shaping factors of domestic water demand as they were identified by the above mentioned research studies in the field of domestic water demand. The following paragraphs present and analyse several social characteristics based on the main findings of a literature review regarding the effect of socioeconomic characteristics on water consumption.

Table 2-2 Summary of shaping factors of domestic water demand and bibliographic references

Shaping factors	References
Age level	Beal et al., 2011b, Campbell et al., 2004, Gilg and Barr, 2006
Income level	Arbues et al, 2003, Kenney et al., 2008, Potter et al, 2010, Beal et al., 2011b, Harlan et al., 2009, Mondejar-Jimenez et al., 2011, Potter et al., 2010, Willis et al., 2009, Campbell et al, 2004, Kemmelmeier et al., 2002
Education level	Mondejar-Jimenez et al., 2011, Gilg and Barr, 2006, Campbell et al., 2004, Kemmelmeier et al., 2002, Gregory and Di Leo, 2003, Jones et al., 2011
Household occupancy	Beal et al., 2011b, Campbell et al., 2009, Willis et al., 2011
Housing type (renting or owning)	Arbues et al., 2003, Campbell et al., 2004, Gregory and Di Leo, 2003, Randolph and Troy, 2008, Harlan et al., 2009
Housing characteristics	Jorgensen et al. (2009), Randolph and Troy (2008), Kenney et al., (2008)
Environmental consciousness (ea)	Mondejar-Jimenez et al., 2011, Gilg and Barr, 2006
Trust in political control	Jorgensen et al. (2009)

A study about household water end use in Australia identified that younger aged households use less water per capita possibly due to the small amount of time young people spent in their house. In addition, households with young children tend to use more water for washing clothes (Beal et al., 2011b). Furthermore, households with elders tend to be more water wise; however, the increased time elders spend inside increases overall water consumption (Campbell et al, 2004). A study about household water consumption in Phoenix (USA) identified that people aged between 17 – 24 years old tend to use more water than those aged 25 – 70 in general (Campbell et al, 2004). Finally, a study conducted in Devon (UK) regarding attitudes towards water saving demonstrated that environmental awareness is positively correlated with age, meaning that people tend to become more environmentally conscious as they age (Gilg and Barr, 2006).

Several studies in the past, covering the ‘80s and ‘90s, have shown positive income elasticity on water demand (Arbues et al, 2003). In addition, Kenney et al (2008) identified a positive correlation between water demand and income level, and concluded that large high income households consume more water in general. This is also the case in Amman, Jordan where high income houses consume water three times more than low income households are, even though low income households receive water subsidies (Potter et al, 2010). However, Beal et al. (2011b) and Harlan et al (2009) concluded that the increased water consumption of large high income houses is mainly a result of household size and overall affluence and not a result of high income level alone. In a similar vain, a study of Spanish households identified that increased income levels does not lead to a decrease in water consumption or an increase in water conservation attitude (Mondejar-Jimenez et al 2011). However, Willis et al (2009) suggested that high income households are in fact more likely to invest in leakage repairs and water efficient appliances thus lowering their water consumption. This finding is in accordance with the recognition that low income households are unable to invest in leakage repairs and water saving appliances. In particular, experts in Phoenix (USA) concluded that a potential 1% increase in households with low income leads to more than 0.01% increase in water consumption, all other parameters held equal and concluded that it would be appropriate to design water conservation policies for low income households (Campbell et al, 2004).

Family size is positively correlated with water consumption, associating households with children with an increased use of washing machines and showers (Beal et al., 2011b). Both Campbell et al (2009) and Willis et al (2011) identified that families, even though big in size, tend to consume less water per person, probably because they have higher environmental awareness and water conservation attitudes (Willis et al, 2011).

Furthermore, house size and house type, are important factors that affect both outdoor and indoor household water demand. Bigger houses probably have more toilets and thus more water demand (Arbues et al, 2003, Campbell et al, 2004). Family houses consume more water than flats (Randolph et al 2008). Apart from house size, the age of the building is also a factor affecting the indoor water usage, since new houses have a higher chance to be more water efficient (Harlan et al, 2009). Rented houses tend to use more water than owned, mainly because residents have no choice in terms of the water related technologies and property owners and developers are usually indifferent in the water efficiency of the house (Randolph and Troy, 2008).

Gilg and Barr (2006) identified that in the UK environmental awareness increases with education level. In addition, Campbell et al (2004) identified that in the USA, the increase of the education level results in an increase in conservation attitudes. These findings are strengthened by Inglehart's suggestions, whose work starting as early as 1971, indicated that "a transformation may be taking place in the political culture of advanced industrial societies. Inglehart's research (1977, 1997 and 2008 among others) proved through questionnaires that "under conditions of prosperity, people become more likely to emphasise 'post-materialist' goals such as belonging, esteem, and aesthetic and intellectual satisfaction" (Inglehart, 2008). Inglehart's post-materialist thesis explained that prolonged periods of prosperity would shift the materialistic needs, which are covered through affluence, towards non-materialistic needs such as environmental concern. This shift happens slowly as population ages through years of affluence (Inglehart, 2008). On the contrary, when a prolonged period of insecurity is in place needs change back to materialistic needs (Inglehart, 2008).

Environmental behaviour, a typical non-materialistic need of interest in our work is defined as the ''the propensity to take actions with pro-environmental intent'' (Stern, 2000). Environmental behaviour has been identified to increase with increasing education and income level (Kemmelmeier et al, 2002). Furthermore specific environmental education is positively related to environmental behaviour (Gregory and Di Leo 2003, Jones et al, 2011).

Gilg and Barr (2006) examined the links between environmental behaviour and water conservation attitudes and between environmental behaviour and socio-demographic characteristics in Devon, UK. Their research identified that people with a strong environmental behaviour tend to conserve more water. Their main findings in terms of the social profile of water conservation behaviour is that people with high environmental consciousness are older with small sized families, a high education level and own their house, and that people with very low environmental consciousness are younger, males, with large sized families that mainly rent their house and have both low income and low educational level.

The above shaping factors of domestic water demand are further corroborated by the qualitative socio-psychological research undertaken within this work (Koutiva et al., 2015) where a panel of water users identified as the main driver of their water demand behaviour to be their intrinsic motivation, created from internal individual values, such as environmental and economic values and life experiences. Panel members described their water use behaviours as a result of experiences during childhood. For example "seeing their grand-parents bringing water from the village's central supply" made them aware of the value of water and the necessity to safeguard it in everyday activities.

Household water demand is intrinsically linked to water using behaviour. Questionnaires or more recently the use of smart meters may provide information regarding the use of the water technologies of a household (Makropoulos et al., 2014). In such questionnaires, it is possible to ask questions regarding attitudes towards the environment in general, including questions that measure environmentalism based on approaches such as the New Ecological Paradigm (Dunlap et al., 2000). It is also possible to include questions on water use habits. However, one must take into consideration that answers to such questions might be biased and unrepresentative of the true water use (who counts how many times they use the toilet? etc.). Household diaries might work better, but even so, it has been identified that households' perception on water use is highly mismatched (Beal et al., 2011a and b). However, a solution could lie upon smart metering, where new technology smart meters gather information regarding the frequency, volume, and time of use of all the water using technologies of a household. An integrated approach using both smart metering and questionnaires of water attitude could give insights into the actual connection between attitude and behaviour (Loureiro et al., 2015).

2.2.3. Domestic water demand management

It is acknowledged by many researchers (Makropoulos et al., 2008, Gleick, 2003, Butler and Memon, 2006, Mitchell, 2006, Brown and Farrell, 2009, Kampragou et al., 2011) that urban water management needs a shift of practices. Water supply requires the replacement of unsustainable technical solutions, like creating ever new reservoirs, abstracting more groundwater, transferring water from other river basins, with the use of alternative water sources (treated, desalinated, and rain-harvested water) and water demand management, including policies that encourage water-use efficiency. This approach is however obstructed by an increased uncertainty mainly due to the necessity to anticipate the reaction of the public to different water demand management measures. Water end users tend to believe that water is abundant, and attribute to it a hedonistic dimension linking its overuse to a higher quality of life. These attributions to water, constitute even more difficult to foresee the effects of different water demand management strategies to water demand behaviour (Koutiva et al., 2015).

In terms of water demand management, there are two main categories of available strategies: price and non-price. Price strategies consist of the manipulation of water prices to reduce water demand. Non-price strategies consist of restrictions, technological approaches such as metering, incentives for water saving devices, leakage reduction, and water reuse, as well as awareness approaches (EEA, 2001). Nevertheless, whatever strategy is applied, it remains undisputed that households' behaviour is the factor that relates population and domestic water consumption (Corbela and Pujol, 2009).

a. Price strategies

The Water Framework Directive (2000/60/EC) requires EU Member States to ensure that users pay for the negative impact of water services on the environment, according to the 'polluter-pays' principle, in order to reduce the impact and promote economic instruments (EEA, 2013). Figure 2-3 presents water prices across cities in EU (GWI, 2011) and the water exploitation index for the corresponding EU countries (EEA, 2010). The Water Exploitation Index (WEI) is an indicator, used by the European Environment Agency, for estimating the vulnerability of a country or river basin due to decreased quantity of water resources in respect of their water use needs. One would expect that countries with a high WEI would have a higher water price (like Spain and Italy). Nevertheless, the comparison might be a bit biased since the water price value is for a city while the WEI is calculated for the whole country.

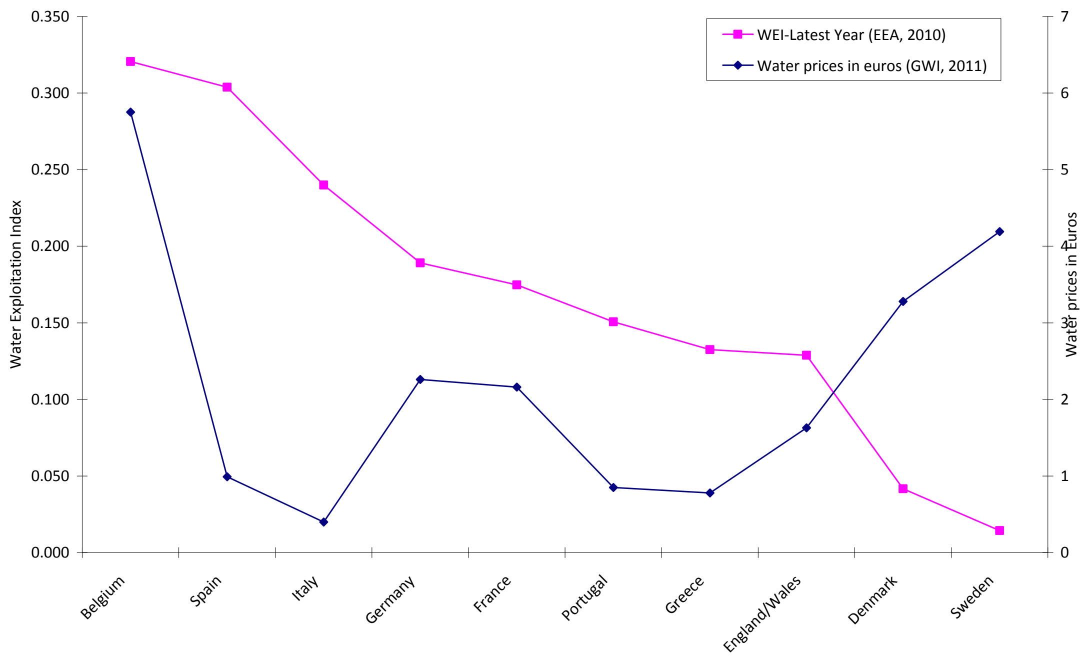


Figure 2-4 Water prices across European cities (per 1000 litres) (GWI, 2011) in comparison to the Water Exploitation Index (EEA, 2010)

Water demand price elasticity has been researched widely for creating water price strategies that would decrease water demand (Kenney et al., 2008). However, as presented in Table 2-3, it has been widely reported that water demand is price inelastic, exhibiting low price elasticity (a price elasticity of -0.5 equals to a 5% decrease of water demand if price is increased by 10%) (EEA, 2013).

Table 2-3 Price elasticity in different countries (EEA, 2013)

Country	Price elasticity
Spain	-0.14 - -0.17
France	-0.12
Greece	-0.40
Cyprus	– 0.79 (for the lowest 10 % of incomes) – 0.39 (for the highest 10 % of incomes)

Gaudin in 2006 identified that the low price elasticity of water demand can be partly attributed to the absence of price information even when increasing block rates are present. The only factor that seems to influence the effect of price information is the existence of drought conditions (the effect of price information was lower in the West and Southwest US were the climate is dry). The application of an econometric model to data taken from roughly 300 utilities across the USA, showed that the inclusion of price-related information to water bills resulted in a price elasticity increase of 30% or more (Gaudin, 2006). It appears that there is a wide gap in research regarding the effect of price information and its transmission from both water utilities and the media.

b. Non-price strategies

Non-price demand management strategies such as water metering, incentives for water saving appliances and awareness raising campaigns have been proposed and/or implemented for various applications (Inman and Jeffrey, 2006).

Water metering has been identified as a prerequisite for effective water demand management policies (EEA, 2013). Imposing restrictions of certain water uses is a reactionary water demand management approach (Beal et al., 2011a) that produces results when imposed. Water restrictions could be capable of creating a household's risk perception, when imposed rarely. However, it has been concluded that in areas where restrictions due to drought conditions are common, households are more willing to deal with short time restrictions rather than pay to alleviate them (Hensher et al., 2006).

In terms of retrofitting water saving appliances, the effectiveness of this measure is entirely due to the ratio of water used between the new and old appliance. In general, toilet and washing machine replacement gives the higher water conservation (Inman and Jeffrey, 2006). Nonetheless, one must take into consideration the behaviour shift of someone that retrofits a water saving appliance (i.e. “since it is water saving I can use it more”).

Changing individual behaviour is central to a sustainable future (Mckenzie-Mohr D., 2000). Awareness raising campaigns are a tool used for educating the public. These campaigns mainly warn the public that water resources are at risk and encourage conservation. However, the public’s uncertainty regarding the actual state of water resources and the frequent use campaigns to preserve the long term state of the resources, may actually decrease the effectiveness of awareness raising campaigns, just as people eventually ignored the boy who cried wolf (Joireman et al., 2009). All the same, researchers (Inman and Jefrey, 2006) have concluded that campaigns work better when relevant climate conditions like drought exist. The reason for this, is that when the risk of water scarcity is low citizens tend to believe that water is affluent, thus paying no attention to water saving awareness campaigns (Howarth and Butler, 2004).

Sustainable resource governance has been a research focus for at least the past decade (Pahl-Wostl et al., 2010). It has been concluded that governance needs to shift towards an adaptive model utilising learning outcomes, altering their processes on the way (Pahl-Wostl et al., 2010). Applying an adaptive approach to water resources management in decision making is challenging since it requires managing both supply and demand of water within a complete urban water cycle framework (Rozos and Makropoulos 2013). Such an approach however, requires tools that can analyse and simulate the complete cycle including both the physical and social dimensions. In order to identify the tools that will allow an adaptive urban water management, complex adaptive systems are explored and the use of statistical mechanics in combinations with social psychology theories in order to model the complex human group processes. The next paragraph presents a short description of Complex Adaptive Systems, their main characteristics and uses them to illustrate the comparability of the domestic water demand dimension of the urban water system to the Complex Adaptive System. These tools are analysed in Chapter 3 and applied in Chapter 4 and 5.

2.3. Complex Adaptive Systems

The study of complex systems has been recognised in recent years as a new interdisciplinary scientific field (Bar-Yam, 1997). The main characteristic of complex systems is that they are composed by many components that interact dynamically in different time and space scales that may exhibit common behaviours (Clemens, 2014). Some examples of such complex systems are governments, families, the human body, the brain, and a person’s psychosocial perspective (Bar-Yam, 1997). These examples have common characteristics such as they are all sets of interacting components, they interact with and adapt to their environment and that they are unique regarding both their components and their behaviours.

The notion of complexity has been around for more than 60 years. Warren Weaver was one of the first scientists to acknowledge complex systems. During World War II, he was head of the Applied Mathematics Panel and was influenced and inspired by many of the top scientists of his era. It was shortly after the World War II, when he published his paper on "Science and Complexity" where he identified the existence of three types of scientific problems: simple problems with few variables, problems of disorganised complexity with numerous variables and problems of organized complexity with a moderate number of variables. Weaver in 1948 predicted that problems of organized complexity might be dealt with by using the power of computers and multi-disciplinary collaborations (Wirth, 2004). These systems of organised complexity are characterised by a self-coordinated interaction between their parts, leading to the emergence of behaviour without however the existence of any central control (Weaver, 1948). More recently, Holland defined that this type of complex systems are composed from: simple components with non-linear interactions between them, with no central control, that present emergent behaviour through hierarchical organisation, information processing and dynamics and are capable to exhibit evolution and learning (Holland, 2006).

The study of complex adaptive systems is about understanding the relationship of the behaviour of parts to the behaviour of a system as a whole (Bar-Yam, 2011). The most common features of complex systems are parallelism, conditional action, modularity, adaptation, and evolution (Holland, 2006). Parallelism describes the large number of the system's components that interact simultaneously with a large numbers of signals. Conditional action portrays the dependence of the actions of the system's components to the received signals, thus following what/if procedures. Modularity represents the ability of the system's components to use groups of rules for addressing new situations rather than having a set of rules for every possible situation. Finally, the system's components exhibit adaptation and evolution, thus changing over time as a result of complex interactions that extend over space and time which may even produce new rules as a result of their adaptation process (Holland, 2006). Another common characteristic of complex systems is emergence, which is the ability to create complex behaviour from the interaction of simple components (Bar-Yam, 1997). The domestic water demand dimension of the urban water system is a complex adaptive system satisfying all the characteristics presented above:

- Parallelism: the domestic water demand dimension of the urban water cycle consists of all domestic water users that consume water autonomously, based on their intrinsic characteristics, interact with the urban water system, its natural dimension, the weather and water resources and its technological dimension, the in-house water appliances, the water distribution and waste water collection systems.

- Conditional action: the domestic water demand dimension is set following what/if procedures that establish the frequency of use of in-house appliances and set water demand. Additionally, the rest of the urban water system follows what/if procedures to meet the set water demand. For example, one domestic users increase the number of showers that they take during hot weather conditions and the water supply managers increase groundwater abstraction in summer months to meet increased water demand or impose water demand management measures if water availability is limited.

- Modularity: the domestic water demand dimension incorporates a variety of actions that are used as a response to the water users' behaviour or the urban water system's requirements. For example, if a household is influenced by a water saving awareness campaign, it may choose to conserve or not water and different ways, levels and time frames to do so, such as choosing between mainstream water saving behaviours, turning off the tap to more efficient methods like installing water saving appliances or even a grey water recycling system.

- Adaptation and evolution: the domestic water demand dimension and the urban water system itself changes over time as a result of complex interactions within the social, natural and technical dimension of the urban water system that extend over space and time and may even produce new rules as a result of these interactions, such as adaptation of new technologies, reaction to new water demand management strategies and others.

- Emergence: the domestic water demand dimension of the urban water system is a result of emergent behaviour of its components, the domestic water users. For example, the seasonality of domestic water demand which at the upper level appears as a monthly trend while when focusing into its components: household consumption and weather conditions, it is possible to identify a variety of possible actions and interactions at the lower levels i.e. household behaviours due to holiday seasons, wet and/or dry conditions effects, gardening, effects of awareness raising campaigns, change of social norms and others.

This juxtaposition, of the domestic water demand dimension of the urban water system and the complex adaptive systems' theoretical characteristics demonstrates the proximity of the urban water system and the domestic water demand component to complex adaptive systems theory. As such, it is within the general field of complex adaptive systems that we seek tools and methods able to capture and quantify emergent properties of human behaviour necessary for our project. The main such method employed in our work is statistical mechanics. The following paragraphs present briefly statistical mechanics used in our proposed methodology.

2.3.1. Statistical mechanics for complex adaptive systems

The emergence of macroscopic phenomena from microscopic behaviour is the main interest of statistical mechanics that try to explain the macroscopic laws of thermodynamics by considering the microscopic application of Newton's laws to the particles that a material is made of (Bar-Yam, 2011).

The following paragraphs give a short presentation of Boltzmann distribution theory (Shell, 2014). In statistical mechanics, a microstate is defined as a state of the system where all the parameters of the components are specified using the energy levels and the state of the particles in terms of quantum numbers. A microstate is identified by all of the microscopic parameters necessary to completely define this state. The probability that this particular state will be realised is given by the fraction of states of the whole system for which the small system attains this state. A macrostate specifies a system in terms of quantities that “average” over the microscopic constituents of the system. Examples of such quantities include the pressure, volume, and temperature of a gas. Such quantities only make sense when considered in a system composed of very large numbers of particles: it makes no sense to talk of the pressure or temperature of a single molecule.

Consider a system of independent molecules that occupy one of the available energy levels ε_0, ε_1, ε_2, …, ε_E where ε_0 is the level with lowest energy. At a given moment, the system will be in a particular configuration where there will be n_0 molecules occupying energy level ε_0, n_1 molecules occupying level ε_1 and so forth. The occupation numbers n_i thereby changes constantly due to the collision between the molecules. Each set of microstates, comprising of all the available energy ε_i occupied by n_i are called ensembles. The average energy of an ensemble is:

$$\bar{E} = \sum_i P(\varepsilon_i) * \varepsilon_i \qquad \text{Equation 2-1}$$

Where $P(\varepsilon_i)$ is the probability of a particle to be in an energy level ε_i and is derived by the Boltzmann distribution that gives the distribution between different energy levels of the particles in a system related to the statistical ensemble of all possible states. The distribution law is dependent on the conditions of the thermodynamic system. There are three standard system definitions, based on the thermodynamic ensemble:

Micro canonical Ensemble : isolated system at equilibrium where each microstate has an equal probability. The system is isolated with fixed energy, E and number of particles, N. The probability is:

$$P(\varepsilon_m) = \frac{\delta_{E_m=E}}{\sum_i \delta_{E_n=E}} \qquad \text{Equation 2-2}$$

where E_m is the total energy of a microstate and δ is the delta function called a Kronecker delta (δ_x), with values of 1 if x is true and 0 otherwise.

Canonical Ensemble: constant temperature system (connected to an infinite heat bath). The system has a fluctuating energy. The probability that a particle has energy ε_m is:

$$P(\varepsilon_m) = \frac{e^{-\beta\varepsilon_m}}{\sum_n e^{-\beta\varepsilon_n}} \qquad \text{Equation 2-3}$$

where β is a fundamental physical constant that equals to $(k\,T)^{-1}$ (the Boltzmann constant multiplied by the systems temperature), and n is all the available energy levels.

Grand Canonical Ensemble: results when a system at fixed volume is coupled to a bath with which it can exchange particles and energy. The probability that a particle has energy ε_m is:

$$P(\varepsilon_m) = \frac{e^{-\beta\varepsilon_m + \beta\mu N_m}}{\sum_N \sum_n e^{-\beta\varepsilon_n + \beta\mu N}} \qquad \text{Equation 2-4}$$

where β is a fundamental physical constant that equals to $(k\,T)^{-1}$ (the Boltzmann constant multiplied by the systems temperature), N is the number of particles, μ is the chemical potential ,and n is all the available energy levels. It is often useful to introduce a quantity $\lambda \equiv \exp[\beta\mu]$ sometimes called the absolute activity or absolute fugacity.

In this research, statistical mechanics are used to study collective social phenomena emerging from the interactions of individuals as elementary units in social structures (Castellano et al., 2009). The application of statistical mechanics to social phenomena is a multidisciplinary field of science. The relation between the physics laws and human behaviour is not new at all. Boltzmann, in 1872, described molecules as individuals that have various states yet the overall properties of gases (or society) remain unaltered, mainly due to the high number of individuals (Ludwig Boltzmann, 1872). Additionally, many scientists and philosophers such as Hobbes, Laplace, Comte and others made observations regarding human group processes that were the result of collective action of individuals, like birth and death rates (Castellano et al., 2009). There is a growing interest in the notion that macroscopic phenomena of social behaviour call for a statistical mechanics approach of the interactions among simple entities that may even be single individuals (Castellano et al., 2009). In many cases, it is possible to assume that the collective behaviour of a crowd of individuals presents aspects of a purely statistical nature (De Martino and Marsili, 2006). Furthermore, it can be assumed that the behaviour of a crowd can be regarded as that of a collective individual making the analysis of the behaviour simpler than in the case of one individual (Galam, 1997).

Nevertheless, two major problems arise in the application of statistical mechanics to social phenomena. One is the lack of information for validating theoretical concepts with real-life data and the other is the oversimplification required for applying statistical mechanics to social life (Castellano et al., 2009, Sobkowicz, 2009). Even so, the application of statistical mechanics requires the oversimplification of social phenomena, looking for qualitative features exhibited by models. Inevitably, the model's results are compared with empirical data to identify the compatibility of real data of macroscopic phenomena with the results of the microscopic modelling of the individuals (Castellano et al., 2009). Statistical mechanics complement social psychology, providing theories of physics and thermodynamics for studying social phenomena.

2.4. Social Psychology Theories

The main difficulty of applying statistical mechanics to social dynamics is the fact that the elementary units are not simple components of well known behaviour, like atoms and molecules, but rather complex individuals that no one knows precisely their behaviour and interaction (Castellano et al., 2009). To tackle this difficulty social psychology was employed in this research to understand the domestic water demand dimension of the urban water system. Social psychology has been defined as “an attempt to understand how the thoughts, feelings, and behaviours of individuals are influenced by the actual, imagined, or implied presence of others” (Allport, 1954).

Social psychologists aim at explaining human behaviour and are interested as well in feelings, thoughts, beliefs, intentions, attitudes, goals, and their inference from behaviours (Hogg and Vaughan, 2011). The latter are not directly observable, contrary to behaviour, and are interesting because they can form or at least influence behaviour (Hogg and Vaughan, 2011).

Some examples of this uncertain connection are prejudice and discrimination; accident awareness and seatbelt use; health risks and smoking; environmental consciousness and resource conservation and others. Additionally, social psychology deals with the way people are influenced by others that are either present or imagined thus, exploring the effect of society to the behaviour of the individual (Hogg and Vaughan, 2011).

In social identity theory, one’s attitude may be a “normative property” of a social network adapted by oneself to “fit-in” (Hogg and Abrams, 1990, Turner, 1991). Therefore, based on the social identity theory, an attitude becomes behaviour more likely if the said attitude is a “normative property” of the social group with which one identifies itself (Hogg and Smith, 2007). The difference between attitudes and social norms is that while attitudes are personal (and when expressed become opinions), social norms are external that represent the expectation of others.

A branch of social psychology is social influence, which studies “the processes whereby attitudes and behaviours are influenced by the real or implied presence of other people” (Hogg and Vaughan, 2011). Social norms are defined as what one perceives as the “acceptable” behaviour within one’s social network. In many cases, social norms that are “contextually salient” may win over one’s intrinsic attitude (Lavine et al., 1998), for example if sports is normative within a student social group then students engage more in sports (feeding the normative nature of sports within the group) (Hogg and Vaugnan, 2011).

Attitude formation can be regarded as a personal process, when an individual learns from experience and as a social process when an individual observes behaviours and/or receives information about behaviours (Hogg and Vaugnan, 2011). This information is usually received by someone’s social network that consists of friends, co-workers, peers, distant and close family members, and a certain group of leaders that someone listens to and respects such as village leaders, trusted politicians, trusted media etc (Acemoglou and Ozdaglar, 2010).

History has illustrated the power of minorities, since it has been argued that if attitudes were influenced only by majorities then social attitudes would have reached homogeneity years ago since people would have been persuaded by the increasing number of majority attitudes (Hogg and Vaughan, 2011). Numerical or power minorities influence attitudes introducing innovations and creating social change (Hogg and Vaughan, 2011). Examples of minority influence are the suffragettes in the 1920s, the anti-Vietnam movement in the 1960s, the anti-nuclear movement in the 1980s, and the Greenpeace effect that increased the public's positive attitude towards the protection of the environment while being a very small in numbers group (Hogg and Vaughan, 2011).

The effectiveness of minorities is attributed to a cognitive change that is produced through a thought process trying to understand the cognitive challenge posed by the novel minority position (Hogg and Vaughan, 2011). A minority refers to both power and number of people and it is recognised that there are two possible ways of a minority influence: with low numbers of people with high powers and with high number of people with low powers (Hogg and Vaugnan, 2011). Minority influence is affected by a cognitive process during which someone assigns a cause to her behaviour and to the behaviour of others (Hogg and Vaugnan, 2011, Hewstone, 1989). It has been recognised that a minority attitude influences the attitude of people if it is perceived as freely chosen exhibiting traits of consistency, consensually, distinct from the majority, unmotivated, and flexible (Hogg and Vaugnan, 2011).

The following paragraphs present three theories that are related to the formation of water demand attitude and subsequently behaviour: complex networks theory, Social Impact Theory (Latane, 1981) and the Theory of Planned Behaviour (Ajzen, 1991). The latter two are complemented in our research by statistical mechanics to model the urban household's domestic water demand behaviour.

2.4.1. Complex Networks Theory

In this research, complex networks are used to represent the processes that influence the attitudes regarding water demand behaviour. Social norms, policy instruments and intrinsic characteristics may be employed for estimating the social impact to the water demand attitude and its change within an urban population (see paragraph on social impact). This research uses the complex networks' characteristics to create the social network of urban households that influences their water demand behaviour.

A network is a set of nodes that are connected with edges. In mathematics, networks are called graphs and are used to model relations between objects (More information regarding probabilistic graphical models can be found in Koller and Friedman (2009)). Euler's famous problem of "Seven bridges of Koningsberg" is regarded as the beginning of the modern graph theory in 1735. The modern form of complex networks theory initiated in the 1950s by Erdos and Renyi, two Hungarian mathematicians (Erdos and Renyi, 1959) that laid down the foundations of the random graph. Even so, it took almost 50 years in order for the complex network science to unveil its potential for assessing complex systems.

In 1998, Watts and Strogatz (Watts and Strogatz, 1998) published in Nature their seminal work on small-world networks and one year later Barabasi and Albert (Barabási and Albert, 1999) published their influential work on scale-free networks. The progress of the complex network scientific field was deeply connected to the evolution of processing power and to the ability to study the properties of large databases of real networks that followed the Internet revolution (Boccaleti et al., 2006). In social sciences, complex networks may be used to represent social interactions by connecting individuals with edges that represent their relationship (Albert et al., 1999). Complex networks have been used to study interactions between individuals, address issues of centrality and connectivity (scenarios and topography of connectivity and influence) (Newman, 2003).

A wide range of complex systems has been described using complex networks. To name a few: the cell which is a network of chemicals linked by chemical reactions, the Internet which is a network of routers and computers connected by physical links, the food chain in a lake which is a network of predator pray interactions, the romance life of college students which is a network of college students and their sexual interactions, the society in general which is a network of people and organisations connected by social interactions and other technical, physical and human complex systems (the brain, journal citations, energy and water infrastructure, friendship etc).

The interdisciplinary nature of complex networks and in particular of their application to social systems has raised over the years a solid scientific discipline that integrates anthropologists, social psychologists and statisticians with its own textbooks like the one by Wasserman (1994) as well as specialized journals like Social Networks published by Elsevier (Boccaleti et al., 2006). While traditionally these systems have been modelled as random graphs, it is increasingly recognized that the topology and evolution of real networks are governed by robust organising principles (Albert and Barabasi, 2002).

One of the most important macroscopic properties of complex networks is the degree distribution, the distribution of the number of connections that each node has. This property of complex networks is used in the following paragraphs to describe the three options of complex network structures: the random network (Erdos and Renyi, 1959), the scale-free network structure (Barabási and Albert, 1999) and the small world structure (Watts and Strogatz, 1998).

The random network structure creates an edge between each pair of nodes with equal probability, independently of other edges (Erdos and Renyi, 1959). The random network presents a binomial or Poisson (for large number of nodes) degree distribution. The main disadvantage of the random network structure is that the majority of the real life networks present a heavy tail in their degree distribution. The realisation that real world networks do not present a homogenous degree distribution was possible only when big data (measurements on large networks) became available in the late 1990's. It turned out that real world networks had a scale-free degree distribution (Szell, 2011).

Milgram in 1967 highlighted the small-world phenomenon by creating an experiment that involved randomly selecting people from different states in the US and recording the path of letters until they reached randomly selected people in another state. This experiment coined the phrase “six degrees of separation” showing that each person is connected with someone else with a chain of other six people. Watts and Strogatz in 1998, proposed a network structure (Figure 2-6) that had a constant number of links and nodes but involved the rewiring of the connections. They proposed a low average path length that meant a low mean number of nodes between any randomly chosen pair of nodes. In addition, they proposed a high clustering coefficient, which meant that when two edges share a node, it is likely that a third edge exists, such that the three edges form a triangle (Watts and Strogatz, 1998). In the small-world network structure, each node is connected to its two nearest and next-nearest neighbours. With a set probability, each edge is reconnected to a node chosen at random. The long-range connections, generated by this process, decrease the distance between the nodes, leading to a small-world phenomenon (Albert and Barabasi, 2002). The main disadvantage of this network structure is that it assumes that the population of nodes and their links remain unchanged and that the only change that happens is the rewiring of the edges (Barabási and Albert, 1999).

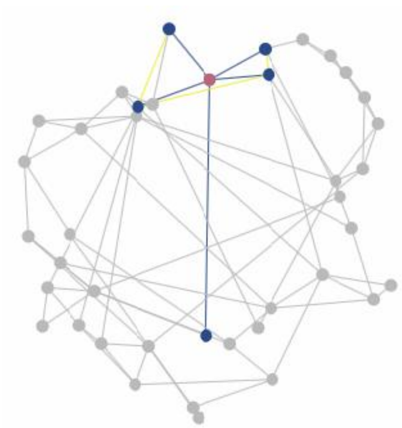


Figure 2-5 Example of a small world network structure (Wilensky, 2009)

Barabási and Albert in 1999 created the scale-free network structure when they observed two properties of real world networks: growth and preferential attachment. Real world networks usually start from a small nucleus of nodes, which increases in number throughout the lifetime of the network (i.e. the World Wide Web, research literature). The newcomers do not connect with a node independently of the receiving node’s degree (random placing of new edges) but rather prefer to connect with those nodes that have a higher degree, thus exhibiting preferential attachment (Figure 2-7). For example, a new research paper is more likely to cite well-known and thus much-cited publications than less-cited and consequently less-known papers (Albert and Barabasi, 2002).

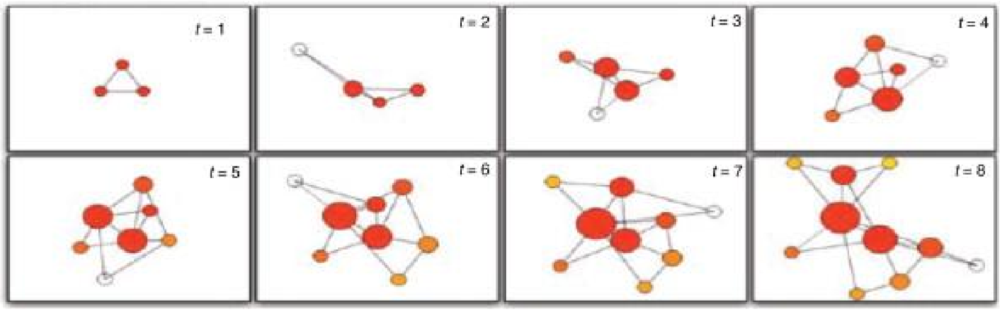


Figure 2-6 Example of a scale-free network structure and how it is created (Uddin et al., 2011)

The type of complex network, scale-free or small-world, depends on the ability of the complex network structure to simulate the evolution of water demand behaviour in the under investigation case. Yet, it has been identified that different social networks follow different complex network structures depending on their intrinsic characteristics (Albert and Barabasi, 2002).

A highly centralised network, such as the scale-free network, allows individuals to have more power, having control over the information transmission towards their nodes (Bodin and Crona, 2009). A highly connected network, such as the small-world, presents a flat influence power structure where each node has an equal number of ties and so equal access to information and resources (Bodin and Crona, 2009). Nevertheless, in large networks of both structures cliques and subgroups may be created, since not all connections have the same influence ability due to differences in social characteristics (Krebs and Holley 2006).

The above introduces the notion of homophily (McPherson et al., 2001) where someone is influenced more by those connections with the same characteristics. In 1997, Axelrod introduced the notion of homophily, where individuals tend to associate and bond with similar others. In sociology, homophily is the principle that a contact between similar people occurs at a higher rate (McPherson et al., 2001). This notion plays a special role, as well, in statistical physics and is called "bounded confidence" and means that if two particles are too far apart, in terms of characteristics, they do not exert any influence on each other (Castellano et al., 2009).

The utilisation of the complex network theory in the proposed modelling methodology can be found in Chapter 4.

2.4.2. Social Impact Theory

Social Impact Theory, first introduced by Latane (1981), was developed to investigate group size and temporal and physical immediacy of minority influence. The emergence of macro-level phenomena from applying the micro-level Social Impact Theory was established by Nowak et al. (1990) and further developed with a probabilistic and statistical mechanical theory of micro-sociological behaviour by Bahr and Passerini (1998).

Based on these theories, the change of someone's opinion (O_i) (positive / negative) is determined by the social impact (I_i) calculated by the following Equation 2-1:

$$I_i = -S_i b - O_i h - \sum_{i,j=1}^{n} \frac{S_j O_j O_i}{d_{i,j}} \qquad \text{Equation 2-5}$$

Where

I_i is the exerted social impact

O_i (positive / negative) is the individual's opinion

S_i is the individual's strength of influence

b is the individual's opinion strength

These three characteristics - opinion, strength of influence and opinion strength - allow more flexibility in describing the interaction process assigning different 'social roles' and 'powers', reflecting social differences (Sobkowizc, 2009).

($\sum_{i,j=1}^{n} \frac{S_j O_j O_i}{d_{i,j}}$) is the individual's i social network influence that includes n other individuals j with each member of the social network having an S_j strength of influence and an O_j opinion.

h is the external influence (h)

Wragg in 2006, estimated the external influence as the influence from mass media adding factors for the media opinion O_M and the media strength of influence S_M. The external influence was formulated as $h = O_i O_M S_M$.

In order to include a degree of randomness in the deterministic force of pressure Kacperski and Holyst (1999) used a rule following Glauber mechanics or the Ising model (Glauber, 1963) an implementation of the Boltzmann distribution to ferromagnetic materials.

Select randomly a number X from a uniform distribution of [0,1] then calculate

$$P_{change} = \frac{\exp\left(-\frac{I_i}{T}\right)}{\exp\left(-\frac{I_i}{T}\right) + \exp\left(\frac{I_i}{T}\right)}$$

If $X < P_{change} \Rightarrow O_i(t+1) = -O_i(t)$

If $X > P_{change} \Rightarrow O_i(t+1) = O_i(t)$ Equation 2-6

Where

P_{change} is the probability of an individual to change its opinion

I_i is the exerted social impact

$O_i(t)$ is the opinion of the individual i at time t

T is the average volatility of social impact. The parameter T is a measure of “social temperature” that captures the susceptibility to change of the average opinion within the simulated population (Kacperski and Holyst, 1999). Contrary to what others until then had proposed, disposition, susceptibility, suggestibility (Johnson and Feinberg, 1977), contagion (LeBon, 1960), social facilitation (Allport, 1954), Bahr and Passerini, in 1998, identified that social temperature is a group and not a personal characteristic averaging a group’s opinion susceptibility to change. Bahr and Passerini (1998) grounded this concept in the fact that as in physics temperature is a “global” characteristic that has no meaning in pair wise interactions (molecular) but is one of the main parameters in group interactions (gases). Analogue to this “social temperature” is only valid in a statistical or average “large” group. High values of T mean that opinions are difficult to change and low values that opinions are highly dependent on social norms (Wragg, 2006).

Sobkowizc in 2009, suggested the expansion of the social impact model by adding a complex network structure and including strengths in the links connecting pairs of individuals. This network could correspond to the physical or psychological 'closeness' of the individuals, or homophily, or the functional/professional relationships. In such situation, even a strong and convincing individual would have less impact on others that are only weakly connected. In this research, in accordance with Apolloni et al. (2009), homophily is included by considering only socio-demographic information since attitudes can be derived from this set of information.

The **Social Impact Theory** (Latane, 1981) that was used to address the effects of society, policies and other external forces to the domestic water users’ behaviour, in correlation with the promotion of pro-environmental behaviour (Aoyagi et al., 2012) and the effect on common pool resources of social norms (Brucks et al., 2007). Social Impact Theory has been used together with cellular automata (Latane, 1996, Nowak and Lewenstein, 1996), agent based models (Holyst et al., 2000, Kacperski and Holyst, 2000) and complex network theory (Aleksiejuk et al., 2002, Sobkowizc, 2003a and 2003b) for a variety of social simulation purposes.

In correlation with the social changes that have been attributed to minority influence, it can be deducted that an attitude change, from negative to positive, regarding water conservation is a product of cognitive processes of thought. Relevant to the water conservation attitudes is pro-environmental behaviour that has been identified to be linked with the minority influence power mainly due to the uncertainty and the lack of validation of its effects (Fell et al., 2009).

In this research, the Social Impact Theory was selected based on the fact that it may be used to investigate minority influence while taking into consideration the effect of minorities, social norms and external influences. The importance of social norms is based on its saliency (Hogg and Vaugnan, 2011) and managing social norms or even creating social norms may increase the water saving behaviour of an urban population (Dinar et al., 1997, Helbing et al., 2010). External influences may be attributed to policies, media and other forces that try to create said normalities.

2.4.3. Theory of Planned Behaviour

Social psychology scientists have identified the existence of inconsistency between attitudes and actual behaviours (Hogg and Vaughan, 2011). However, a consistency in attitude-behaviour is evident when the attitude is accessible, publicly available (expressed through interviews or questionnaires) and an individual may identify itself to a group where such attitude is normative (Hogg and Vaughan, 2011). The Theory of Reasoned Action (Ajzen and Fishbein, 1977) and later its extension, the Theory of Planned Behaviour (Ajzen, 1985), emerged to support the notion that attitude and behaviour are not correlated in a one-to-one fashion but there are more factors that need to be taken into consideration in order to link beliefs to intentions to behaviours. These factors include: subjective norms, attitudes, and perceived behavioural control that act to the behavioural intention of an individual to perform a behaviour (Figure 2-8).The stronger the intention the more likely is a behaviour to be performed (Ajzen, 1991).

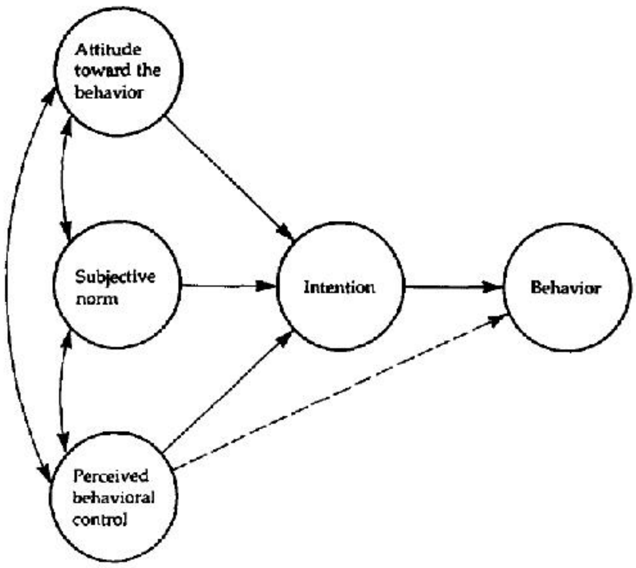


Figure 2-7 Theory of Planned Behaviour (Ajzen, 1991)

The Theory of Planned Behaviour has been used to understand household water conservation (Fielding et al., 2010, Hurlimann et al., 2009, Clark and Finley, 2007, Harlan et al., 2009, Lam, 2006). Lam in 2006 used the Theory of Planned Behaviour to try and predict the intention to save water and identified that the subjective effectiveness of alternative solutions and the response efficacy had major effects on people's intentions.

Fielding et al., in 2010, used the Theory of Planned Behaviour to provide a framework for investigating household water use in combination with other important drivers of household water conservation such as water use habits, household culture and community identification.

Hurlimann et al. (2009) did an extensive literature review regarding the use of the Theory of Planned Behaviour in evaluating the drivers of water demand. Among others they reported a significant positive correlation of the Theory of Planned Behaviour variables with water conservation intention in a study about the effect of environmental attitudes and concerns over future shortage of water on conservation, conducted in Blagoevgard, Bulgaria (Clark and Finley, 2007).

Additionally, a study held in California (Trumbo and O'Keefe, 2001 & 2005) considered socio-demographics, environmental values and information effects, in addition to attitudes, social norms and perceived behavioural control.

Furthermore, Jorgensen et al., in 2009, used the Theory of Planned Behaviour to create an integrated social and economic model of household consumption by combining housing, economic and social characteristics in estimating the behavioural intention towards water conservation.

Based on the above, researchers have used the Theory of Planned Behaviour as a plan for identifying the shaping factors of the behavioural intention of domestic water users. In this research the behavioural intention for low, high or no conservation behaviour is defined (see Chapter 4). In accordance with the Boltzmann distribution, the formula of behavioural intention is used to calculate an "energy" for each one of three assumed discrete microstates of water demand with low, high and zero conservation for each household. This presupposes that each household belongs to a "thermodynamic system" that is interacting with its surroundings in this case composed of its social network, media and environment, exchanging "energy". Thus, the thermodynamic system of the household is represented by a canonical ensemble of system states and the probability of adopting a water conservation level follows the rule of a canonical ensemble , see Equation 2-3. Assuming that the behavioural intention function integrates the negative thermodynamic beta (β) the microstates' probabilities for a household are given by the following equation:

$$P_i = \frac{\exp(BI_i)}{Z} \qquad \text{Equation 2-7}$$

where i represents the different water demand microstates of (low, high and zero water conservation) BI_i represents the Behavioural Intention function of each water demand microstate and Z is the partition function that provides a normalization factor for the probability distribution:

$$Z = \sum_i \exp(BI_i) \qquad \text{Equation 2-8}$$

Chapter 4 presents the parameters that take part in the proposed behavioural intention function. Chapter 5 presents the integration of this function into the designed modelling platform. Finally, in Chapter 6, the ability of the proposed behavioural intention function to estimate the urban household's behaviour is tested using the drought period of 1988 – 1994 in Athens, Greece.

2.5. Summary

We adopt a multidisciplinary approach towards a modelling methodology able to assess the effects of water demand management strategies on the urban water system. In this chapter we briefly presented theories from several scientific fields that were integrated to create a solid theoretical framework. The following chapter presents the tools that were developed or customised to implement this theoretical framework into a decision making tool.

Chapter 3. Tools and Methods

3.1. Introduction

Water systems evolve through time, changing constantly in an unrepeatable fashion (Koutsoyiannis et al., 2008). Additionally, changing socio-economic conditions increase even more the uncertainty of the outcome of the water resources management decisions (Pahl-Wostl et al., 2007). To address this increased uncertainty, the field of hydroinformatics shifted from classical methodologies to modern computational tools as means to simulate reasoning and decision making processes of various stakeholders. “Experimental” approaches, such as the one proposed by adaptive management, give the opportunity to better understand the way the system may react to changes and supports incremental adjustments on the management decisions based on these learning outcomes. Water resources management experiments may be developed using models that allow investigation of behavioural patterns, linkages and feedback loops to the management and performance of water systems (van der Belt et al., 2009).

The following paragraphs present the tools used in this PhD research. These tools are separated into two distinct categories: (a) computational: agent based modelling and urban water cycle management tools and (b) non-computational: social psychology methods. For the purposes of this research, both quantitative and qualitative social research methods are proposed to gather information regarding the water demand attitudes and their link to behaviours of water users. Additionally, agent based modelling is selected to simulate the urban household’s water demand behaviour. Finally, the Urban Water Optioneering Tool (UWOT) was chosen to support both the assessment of the domestic water demand evolution through the modelling of in-house water appliances and the urban water system’s response to water demand management policies and changing domestic water users’ behaviours. Figure 3-1 summarises the tools and methods used for the purposes of this research.

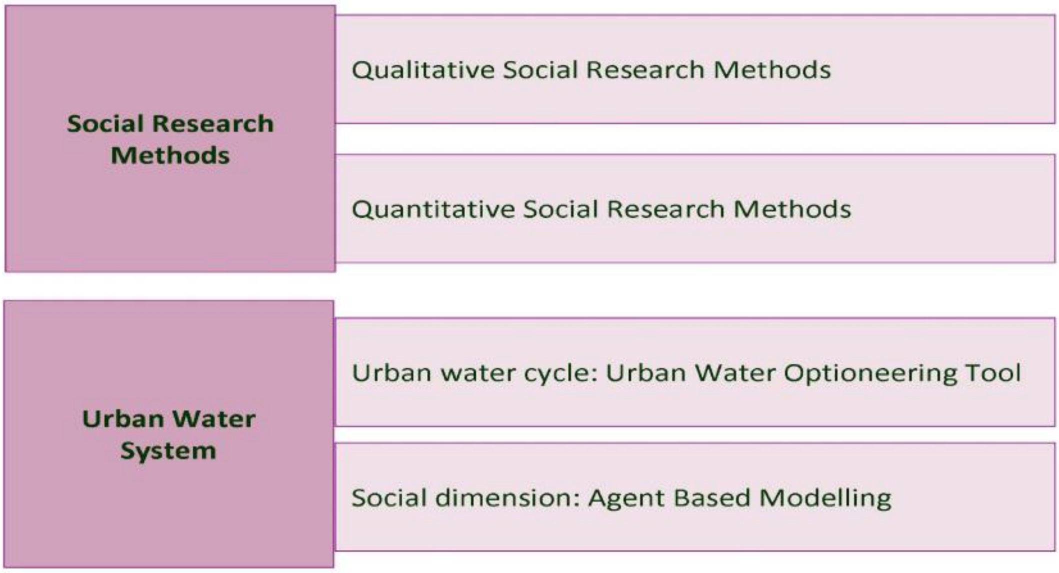


Figure 3-1 Schematic representation of the methods and tools used in this research

3.2. Social psychology methods

Socio-economic uncertainty and changing patterns of ordinary consumption create an unpredictable context for urban water resources introducing new challenges for water resources research, planning and policy (Gerakopoulou and Makropoulos, 2013). Social sciences could contribute to the exploration of current uncertainties by investigating the difficult to predict decision making process. They could aim at connecting environmental, social and technological changes to the meanings of water in a more psychosocial and ethnographic sense. Thus their results would adjust the research interest in the 'here and now' of consumers water use reality (Gerakopoulou and Makropoulos, 2013). This is significant as despite a plethora of research on water use from psychological and economic related disciplines it is still relatively unknown whether people's attitudes towards the environment and water, people's intentions to conserve water or install water efficient devices led to actual sustained water conservation and savings (Russell and Fielding, 2010). In that context, it is difficult to interpret water demand behavioural patterns and the connections of this demand to current and shifting urban infrastructure (Browne et al., 2013).

The investigation of behavioural patterns may benefit by the employment of quantitative and qualitative methods of social psychology research. Qualitative tools, such as semi-structured interviews and methods, including interpretative phenomenological analysis, discourse analysis, biographical approaches, ethnography and others (Smith, 2008), will allow an in depth research of the shaping factors of attitudes, perceptions, cognitions, attributions and their link to behaviour and decision making. In addition, quantitative methods such as questionnaires will allow the gathering of raw data to describe water consumption habits (Wisker, 2007).

3.2.1. Quantitative social research methods

The lack of quantitative data regarding people's attitudes and behaviours towards water may be addressed using a survey. The following paragraphs present a set of questions that can be used in surveys to gather information regarding household water demand attitudes and behaviours. Specifically, the New Ecological Paradigm (NEP) scale, designed by Dunlap et al. (2000), is proposed as a means to measure environmental attitudes. This method consists of 15 questions for estimating the NEP scale as follows:

1. We are approaching the limit of the number of people the earth can support
2. Humans have the right to modify the natural environment to suit their needs
3. When humans interfere with nature it often produces disastrous consequences
4. Human ingenuity will insure that we do NOT make the earth unliveable
5. Humans are severely abusing the environment
6. The earth has plenty of natural resources if we just learn how to develop them
7. Plants and animals have as much right as humans to exist
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations
9. Despite our special abilities humans are still subject to the laws of nature
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated
11. The earth is like a spaceship with very limited room and resources
12. Humans were meant to rule over the rest of nature
13. The balance of nature is very delicate and easily upset
14. Humans will eventually learn enough about how nature works to be able to control it
15. If things continue on their present course, we will soon experience a major ecological catastrophe

These questions cover five dimensions of environmental issues, as follows: reality of limits to growth (questions: 1,6,11); anti-anthropocentrism (questions: 2,7,12); fragility of nature's balance (questions: 3,8,13); rejection of excemptionalism (questions: 4,9,14); and possibility of ecocrisis (questions: 5,10,15). Respondents are offered five answer options from Strongly agree (2) to Strongly disagree (-2) to indicate their level of agreement. The sum of the responses indicates the total NEP score. Based on previous studies (Aronson et al., 2005) mean NEP score is 53.3, with a higher score indicating a pro-environmental behaviour.

Furthermore, environmental concern has been shown to be a good predictor of pro-environmental behaviour (Dolnicar et al., 2011) and the following questions may be used for measuring this concern:

- How aware do you think you are regarding environmental issues? (very, somewhat, little, not at all)
- How informed do you believe you are regarding environmental issues? (very, somewhat, little, not at all)
- To what extent are you concerned about the situation of the environment in general? (1 (little) – 10 (very much)

The attitude towards water conservation may be estimated using the following questions regarding water conservation (Dolnicar et al., 2011). Respondents are offered five answer options from Strongly agree (5) to Strongly disagree (1) to indicate their level of agreement. The questions are divided into two categories: those that the strongly one agrees with, the more positive is towards water conservation (4, 7, 8, 12) and the rest that that the strongly one disagrees with, the more positive is towards water conservation.

1. I shouldn't conserve water if the rest of my community overuses
2. I will conserve water only if it is imposed to me by regulations
3. Farmers have a greater impact on water resources than domestic water users
4. I am willing to spend more money to acquire water saving appliances
5. I am trying to conserve water only when it helps to lower my utility bills.
6. Households like mine should not be blamed for environmental problems caused by water demand.
7. Use of alternative water resources (such as desalinated and reclaimed water) is the best way to combat water scarcity.
8. Water conservation is necessary because of water scarcity
9. I will conserve water only if the rest of the community does
10. I will conserve water only if it is imposed to me by regulations
11. I am using the proper amount of water because my water bill is low
12. Water is more important to me than to the rest of the community
13. I can use as much water as I want from my well/borehole
14. Spending money for water saving appliances is not a clever investment
15. Water scarcity is created due to the overexploitation of the resource from everybody else in the community

Moreover, a survey may include questions regarding water billing period (monthly, bimonthly, quarterly etc) and actual water bill in terms of water (cubic meters) and euros charged. Additionally, the respondents may be asked to identify the water using appliances and amenities that their house has by selecting them from a list. Subsequently, the respondents may be asked to select the frequency of use of the appliances and amenities of their household and the frequencies of use of them if they were aiming at a low or high water conservation. These questions are included in an effort to identify the percentage change of the appliances' frequency of use for different levels of water conservation. Additional water conservation behaviour (Gilg and Barr, 2006) is possible to be assessed using the following questions.:

Water conservation behaviours

1. Reduce the time of showering / bathing
2. Make sure that the taps don't drip
3. Turn off tap when soaping up
4. Turn off tap when cleaning teeth/washing hands
5. Turn off tap when washing dishes
6. Reuse water from wash basin without the installation of equipment (gather water in a bucket when using the wash basin)
7. Use of a brick inside the toilet flush to reduce the capacity
8. Check for water leakages and repair them
9. Install a rain water harvesting system
10. Install a grey water recycling system

Finally, the respondents may be asked to identify the degree of influence from various sources regarding water use behaviour. The questionnaire concludes by requesting a number of socio-demographic characteristics.

3.2.2. Qualitative social research methods

A qualitative socio-psychological research may also be employed to identify the shaping factors of domestic water demand behaviour. The method should employ a narrative structure (Elliot, 2005) were the participants are asked semi structured questions like "Tell me about your experiences regarding water consumption" and other questions in order to lead the narration towards water demand behaviour, attitudes and their shaping factors.

Qualitative approaches aim to explore 'research questions' about individuals' experiences and perceptions, to come up with the essence of meanings and to understand how particular phenomena are generated in particular socio-cultural and environmental contexts (Koutiva et al., 2015). In the present research, the aim of the qualitative study is to explore the perceptions, cognitions, attitudes, everyday practices, imaginary material and beliefs of consumers on household water use, water consumption and the value of water resources.

The data collected are subjected to thematic content analysis with the aim to understand in depth the content and complexity of meanings rather beginning by examining in detail at the transcript of one interview before moving on to examine the others, case by case. Qualitative analysis is not based on frequencies, but instead on identifying common themes in the data. The thematic content analysis allows the emergence of connections and meaningful associations between themes that clustered together. As an adjunct to the process of clustering, directories of the participant's phrases that support related themes may be compiled and examples of comments reported as indicative reference.

3.3. Urban Water Optioneering Tool

The urban water system is made up by three technical components: water supply, wastewater disposal and rainwater drainage (Makropoulos et al., 2008). Urban water management tools have been developed to model the interactions between these technical components as well as the physical environment of the urban water system. Examples of such urban water management tools are the Aquacycle (Mitchell et al., 2001), Hydronomeas (Koutsoyiannis et al., 2002), eWater Source IMS (Welsh et al., 2013) and UWOT (Makropoulos et al., 2008). The following paragraphs provide a short presentation of the first three models and a more thorough one of UWOT. UWOT has been selected as this research's urban water modelling tool, however any other tool could be used in its place, with appropriate modifications of the modelling methodology.

Aquacycle (Mitchell et al. 2001), has been developed to provide a holistic urban water system modelling framework incorporating modelling tools for water supply, wastewater disposal and storm water drainage. The main inputs of the tool are: the site description; the indoor water use profile; daily precipitation; and potential evaporation series. The model's outputs are: the stormwater, wastewater, and imported water use; the stormwater and wastewater yield; the evapotranspiration; the storage status; and the performance of alternative supply sources. Aquacycle uses a water use profile to model the indoor household water demand, by applying litres per day for the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy. In addition, Duncan and Mitchell (2008) developed a stochastic generator for domestic water demand that simulates household water demands for a range of end uses, representing short time scale variability.

Koutsoyiannis et al. (2002) developed a decision support system (DSS) that consists of several components (modules) such as an information subsystem composed by a database, a GIS, a telemetric system, the stochastic hydrologic simulator (named Castalia) and the hydrosystem simulator and optimiser (named Hydronomeas). The main aim of the DSS is to help seek the optimal management policy (OMP) of the water resource system. Hydronomeas does not model water demand but rather uses it as one of the system's operating targets. Water demand is an input to the DSS in the form either of time series or of mean and maximum values of water demand.

The Urban Water Optioneering Tool (UWOT) provides a common modelling environment for the whole urban water cycle from source to tap and back (Rozos and Makropoulos 2013). In Figure 3-2 an abstract representation of the urban water system is presented with the upper part showing the external water supply system that includes the upstream hydrosystem and the storage, transfer and treatment of raw water and the bottom part representing the internal urban water system that includes the water users (domestic, industrial, agricultural, municipal and others) and the downstream hydrosystem that receives the treated and untreated wastewater and storm water flows. UWOT utilises a bottom up approach, simulating water demand generated by the frequency of use of household appliances, aggregating those at the household, neighbourhood and city levels and then routing this demand all the way to the water sources (Rozos and Makropoulos, 2012).

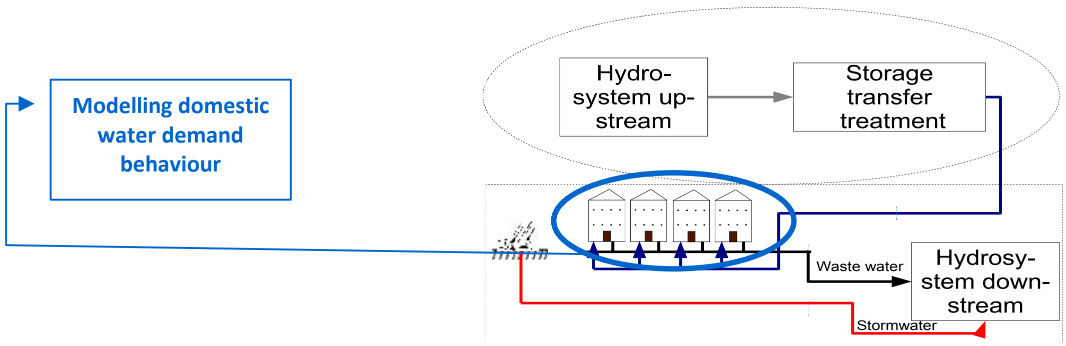


Figure 3-2 Abstract representation of the urban water cycle (Rozos and Makropoulos, 2013)

UWOT was selected because of its ability to simulate the complete urban water cycle and to model demands at the level at which domestic end users actually interact with the water system (at the appliance level). As such UWOT forms the ideal interface between water resources and social actors (to be specifically targeted in this research).

In this work, the end-users' modules and the external hydrosystem modules of UWOT are employed. The end-users module is used to translate water demand behaviour, represented here by the frequency of use of individual household appliances that use water, such as toilets, washing machines, and showers, into domestic water demand. The external hydrosystem module is used to assess the response of the hydrosystem to different scenarios of water demand management strategies.

UWOT's parameterisation requires identification of household appliances and an estimation of their frequency of use for the different water user types and water demand behaviour states (Rozos and Makropoulos, 2013, Beal and Steward, 2013, Grant, 2006). The appliances' frequencies of use also account for annual and seasonal trends. Seasonal variability is accounted for by changing the frequency of use of appliances that are affected by weather changes such as the shower, the washing machine and outside uses (Rozos and Makropoulos, 2013). The annual trend is incorporated across all in-house water appliances to capture the effects of a changing quality of life (under the assumption that as quality of life increases so does overall frequency of use of water appliances). Water demand variability due to a water saving behaviour needs to be included as well within the in-house appliances' frequency of uses for different conservation levels.

The proposed methodology interferes with the standard UWOT modelling process by modelling externally the domestic water demand behaviour of urban households (Figure 3-2 pink callout) and reintroducing the domestic water demand volume for identifying its effect to the external hydrosystem.

3.4. Agent Based Modelling

3.4.1. Support of ABM selection

A main challenge for hydroinformatic tools is the need to model domestic water demand. The estimation of urban water demand may follow one of four classic methodologies (Baumann et al., 1998, Billings and Jones, 1996): per capita; extrapolation; end use; causal models, and four modern methodologies (Galan et al., 2009, Koutiva and Makropoulos, 2011): neural networks, Bayesian belief networks, system dynamics and agent based modelling.

Per capita estimation is the simplest and "oldest" methodology of all. For example, Germanopoulos (1990) used this methodology to estimate Athens domestic water use. This was achieved by forecasting future population and quality of life conditions. The results of these forecasts were used for estimating per capita water demand. Additionally, the multiplication of these forecasts provided the overall water use. However, extrapolation techniques are very simple, since they estimate water demand assuming that future water demand can be determined by water demand trends of the past (Baumann et al., 1998).

End use estimation decomposes domestic water demand to all the different water appliances that a household uses. A big drawback of this methodology is the time and money consuming methods (social research, questionnaires, interviews etc) that is required in order to gather all the necessary data. However, the introduction of smart metering decreases the time and cost of the information extraction opening new opportunities for end use models. A recent end use study (Willis et al., 2011) was able to identify different habits regarding the use of water appliances between different levels of environmental aware households with the use of both smart meters and extensive social research (questionnaires, interviews etc.).

Causal models try to identify the different explanatory variables that take part in shaping urban domestic water demand. These models have provided a great insight on the shaping factors of urban water demand (Arbués et al., 2003, Barrett, 2004, Beal et al., 2011, Campbell et al., 2004, Fontdecaba et al., 2011, Harlan et al., 2009, Jones et al., 2011, Mondejar-Jimenez et al., 2011, Randolph and Troy, 2008, Willis et al., 2011, Koutiva and Makropoulos, 2012). For example, Mylopoulos et al. (2009) used a causal model to create an econometric function for Thessalonica's domestic water demand and its response to price changes.

The field of Computational Intelligence (CI) has produced applications that vary from applications for logical reasoning to playing chess and diagnosing diseases. The common features of all these applications are that they model and perceive the world within which they act given a specific goal; and they learn based on past experience (Russell and Norvig, 2010). On this basis, the most relevant sub-fields of Computational intelligence (CI) to hydroinformatics are, among others: Artificial Neural Networks; Bayesian Belief Networks, Systems Dynamics Modelling and Agent Based Modelling (Solomatine and Ostfeld, 2008).

Artificial neural networks (ANN) are inspired by the biological nervous systems imitating the ability of people to learn by example. The main characteristic of ANN is that non-linear elements of the network can be trained to adapt to input-output training pairs of available data (Nillson, 1998). ANNs are capable to gain knowledge by extracting patterns and detecting trends from available data (Barden, 2003). The main advantages of ANNs are their abilities to derive conclusions from insufficient data; adaptive learning; self organisation, pattern completion and real time operation (Barden, 2003). ANNs have been used lately (Firat et al., 2008, Msiza et al., 2008) in estimating the short term evolution of domestic water demand. In addition, ANNs are used for creating Data Driven Models of the water system (Fu et al., 2007; Solomatine, 2008). Such models have been utilised in order to forecast flow (Khalil et al., 2005; Conrads et al., 2007) and water demand (Firat et al., 2008; Msiza et al., 2008). However, their main disadvantage is the inability of this methodology to include explanatory or causal variables (Galan et al., 2009).

Bayesian Belief Networks (BBN) can simulate physical phenomena under uncertainty, estimating, for example, future river flows under changing climatic conditions (Henriksen et al., 2007). A BBN is a graphical structure of interconnected nodes representing a set of variables and their links represent the relationship between these variables (Van der Belt et al., 2009). Nonetheless, BBNs are acyclic and do not support feedback loops (Jensen, 2001). Bromley et al. (2005), in the MERIT project, developed BBNs in order to investigate water demand and conflicts in different areas (UK, Italy & Spain). Furthermore, BBNs can be combined and produce an Object-Oriented Bayesian Belief Network (OOBBN) which basically links different BBNs together in order to transfer information between them (Koller et al., 1997). Molina et al. (2010) developed a Decision Support System (DSS) with the integration of Object-oriented Bayesian Belief Networks for representing a complex water system supplied by four groundwater aquifers in the Altiplano region (Murcia, Southern Spain).

System Dynamics Modelling surfaced in the 1970s when the World3 model was developed in MIT and the Club of Rome's report "Limits to Growth" presented alternative development scenarios and their sustainability (Meadows et al., 1972). System Dynamics Modelling (SDM) is based on the notion that a system's structure simulating the positive and negative relationships between variables, feedback loops, system archetypes, and delays is sufficient in order to observe and predict its behaviour (Winz et al., 2007). SDM is flexible, user-friendly and transparent and can be a valuable tool for analysing complex interdisciplinary problems for decision-making (Winz et al., 2007). Stave (2003) created a System Dynamics Model for the water demand and supply in Las Vegas and used it in order to inform the public about different water policy scenarios. Simonovic has published on the assessment of global water resources through the WorldWater model and concluded that global models based on system dynamics can provide valuable understanding of the drivers of change in water use (Simonovic, 2009). Baki et al. (2012) introduced a methodology for coupling SDMs with agent based modelling for modelling the urban water system response to water scarcity.

Agent Based Modelling (ABM) is a computational intelligence application that is based on agents which are "computer systems situated in some environment, capable of autonomous action in this environment in order to meet its design objectives" (Wooldridge, 1999). Agents consist of states and rules and have clearly defined boundaries and interfaces (van Dam et al., 2013). They are able to react on their own based on the input they receive from both their environment and other agents and these actions may alter their own state or that of the environment or even of other agents based on the behavioural rules they follow (Van Dam et al., 2013). ABM reduces the complexity of a problem by representing a system using sub-groups, associating an independent intelligent agent to each group, providing rules for action to each agent and coordinating their activities and interactions (Bousquet et al., 1999). In terms of complexity, agents may be categorised into deliberative and reactive. Deliberative agents are complex mental models that operate based on their "given" belief-desire-intention rules. Reactive agents are used mainly for the simulation of life - and the natural systems - with one main goal, viability, and are based only on simple interactions of agents with their environment (Gandon, 2002). Agent based modelling (ABM) may address problems that concern emergence arising from interactions between a system's individual components and their environment (Grimm and Railsback, 2013).

ABM is slowly gaining ground in the water sciences field. One of the first published studies, in the field of water, was that on the coordination for water management in the Balinese water temple networks (Lansing and Kremer, 1994). Following this example several projects have been developed ever since creating ABMs that address social and natural interactions. The CATCHSCAPE project, used an ABM for simulating social dynamics for different control levels (individuals, agricultural schemes and central) in a catchment in North Thailand (Becu et al., 2003). The DAWN DSS, created an ABM for simulating the consumers' social behaviour and combined it with a conventional econometric model for evaluating water-pricing policies (Athanasiadis et al., 2005). The NeWater project developed an ABM to explore mechanisms of resilience in the Amudarya basin (Schluter and Pahl-Wostl, 2007). The DANUBIA DSS used an ABM for simulating the behaviour of domestic water users and the water supply sector in the Upper Danube Catchment in Germany (Barthel et al., 2008)). Janmaat and Anputhas (2010) investigated the coupling of MIKE-SHE, for hydrological modelling, with REPAST's SWARM agent-based modelling toolkit, for land-use change, for investigating the impacts of climate change in the Okanagan River System in British Columbia. Finally, an ABM was created for simulating domestic water demand using the Valladolid urban area as a case study (Galan et al., 2009). Linkola et al., (2013) developed an agent based model that comparing households' habits using water appliances in the U.S.A. and in the Netherlands. Kock B.E. (2008) created two agent-based models of society and hydrology for Albacete, Spain, and for the Snake River, eastern Idaho, USA to explore whether an expanding institutional capacity would lead to reduced water users' conflict levels. Nikolic et al. (2013) incorporate a system dynamics simulation to an agent based model to analyse the spatial and temporal dynamics of water resources systems.

The above tools can be included in an integrated decision support system to allow experimentation with 'what if' scenarios where changes in socio-economic parameters (such as demand elasticity or technology uptake rates) could then feedback to the decision process. These integrated DSSs may be created using modelling frameworks that can link together different components (Rizzoli et al., 2006; Argent et al. 2006). However, a substantial rebuilding of integrated models is often required in order to be included in a common modelling platform (Harou et al., 2010).

The reviewed tools provide unique traits that could be useful in representing the socio-economic element in experiments that support the adaptive approach of water resources management. Table 3-1 illustrates an summary of the ability of the different CI tools reviewed to represent the socio-economic element of the water system.

Table 3-1 Scoreboard of the ability of the different computational intelligence tools to represent the characteristics of the socio-economic element of the water system

CI tools	Characteristics of the socio-economic element (Macy et al., 2001)		
	Complex	Non linear and Path-dependent	Self-organisation
ABM	All of the reviewed CI tools are able to represent complex systems and their reactions either by observing available data or through adapting expert knowledge	Agents are complex mental models that operate based on their “given” belief-desire-intention rules	Agents decide how to meet their set belief-desire-intention goal. However, the different agent categories (individual, institution etc) need to be set.
ANN		Having emerged from the effort to mimic the human brain ANNs are by nature capable for non-linear and path-dependent thinking	ANNs can be trained by observing data. However data for the socioeconomic parameter are scarce and mainly qualitative.
BBN		BBNs demonstrate non-linear and path-dependent thinking however they are acyclic and unable to feedback knowledge	Self-organisation is possible depending on the software used
SDM		SDM consists of different variables that demonstrate non-linear and path-dependent thinking	SDM depends on the conceptualisation and design of the system. However, the system’s variables can be dynamic and thus able for self-organisation

Figure 3-3 presents a qualitative ranking of these CI tools based on their ability to represent the socio-economic element of the water system and their state-of-the-art use in water resources management.

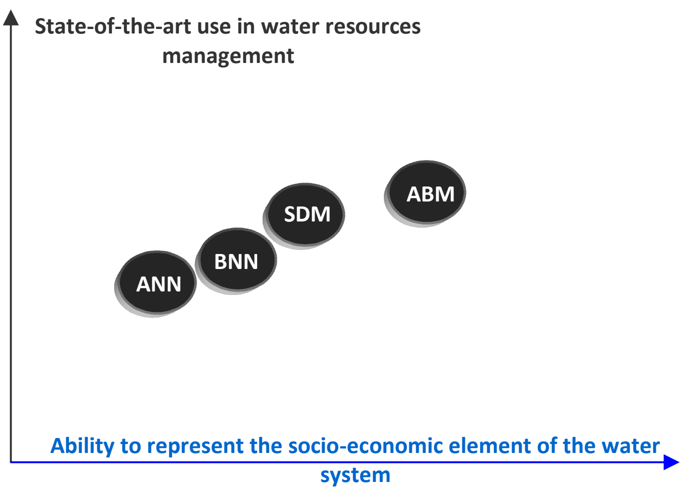


Figure 3-3 Computational intelligence tools scoring based on their ability to represent the socio-economic element of the water system and their state-of-the-art use in water resources management

Addressing domestic water behaviour and its interactions with the urban water system is challenging since human group processes are "complex, nonlinear, path dependent and self-organizing" (Macy and Willer, 2001). The complex adaptive nature of the urban water system (as discussed in Chapter 2) is better modelled using Agent Based Modelling as proposed by a several researchers (Van Dam et al., 2013, Nilsson and Darley, 2006, Borshchev and Filippov, 2004, Tesfatsion, 2003, Railsback, 2001). ABM is a contemporary computational intelligence tool that is capable to capture complex system characteristics of coupled socio-environmental systems (Filatova et al., 2013). This is consistent with the growing realisation that Decision Support Systems for water resources management need to move towards a role of "thinking platforms" supporting a variety of issues and linking the socio-economic environment with both the engineering/technical infrastructure and the natural resource (Makropoulos, 2014).

The above review and the comparison between the different computational intelligence tools that are available for simulating the domestic water demand component of the urban water system, suggest that great promise in terms of addressing the socio-economic element of the water system and supporting adaptive water resources management lies with Agent Based Modelling. This conclusion is also enhanced by the discussion of Wheater et al. (2007) who suggest that ABM is able to address the need for dynamic interaction of the socio-economic element with the water system.

3.4.2. Selection of ABM software

In the 1940s the cellular automata (CA) approach was introduced by John von Neumann and Stanislaw Ulam. It required almost 30 years to take advantage of computer power and in 1970 John Horton Conway a British mathematician from the University of Cambridge developed a simulation game named "Game of Life" (Gardner, 1970). Thomas Schelling (Schelling, 1971) created in 1971 his segregation model that is still being researched by many (Vinkovic and Kirman, 2006, Dall'Asta et al., 2008, Gauvin et al., 2009). That was the "birth" of contemporary cellular automata that later evolved into agent based modelling. The increase in computer power led to a new era of simulation games such as the Robert Axelrod's Prisoner's dilemma (1980), Graig Reynolds' Boids (1987) and Epstein and Axtell's Sugarscape (1995). Even computer games were developed where the player has a virtual world to build, such as SimCity (http://www.simcity.com/) and The Sims (http://thesims.ea.com/) (Gilbert, 2008).

There is a wide variety of available agent based modelling toolkits. An ABM toolkits review analysed 53 different ABM platforms based on five characteristics: programming language; operating system; type of license; intended primary domain; and user support, with the aim to assist ABM users in finding the toolkit that matches their needs (Nikolai and Madey, 2009). Out of these 53 ABM platforms the three mostly used are the NetLogo, Swarm and Repast modelling platforms.

NetLogo is an open modelling platform held by and developed at the Centre for Connected Learning and Computer-Based Modelling at the Northwestern University, Illinois. NetLogo is a functional programming language embedded in its own integrated, interactive environment (Tisue and Wilenski, 2004). The agents in NetLogo, named turtles, have positions within the environment (patches), personal variables and follow user defined rules (Wilenski, 1999). One of the main advantages of the NetLogo agent based modelling language is that it is an easy to learn, easy to understand programming language allowing researchers to easily communicate their created models (Tisue and Wilensky, 2004). Nevertheless, this ease of use, sometimes create setbacks, especially in error checking procedures of the code itself, yet NetLogo provides tools for syntax and run-error checking (Grimm and Railsback, 2013). NetLogo includes several extensions such as for the incorporation of R language commands, for the creation of complex networks and for the integration of Geographical Information Systems (GIS). The user community of NetLogo is quite big providing both a database with many agent based models (http://ccl.northwestern.edu/netlogo/ models/community/) and a forum for problem solving (https://groups.yahoo.com/neo/ groups/netlogo-users/info). In addition it includes a tool for setting up experiments and allowing the investigation of the effect of changing variables to the model's results, supporting model's sensitivity analysis, the Behaviour Space tool. Finally, the NetLogo modelling platform is possible to run headless, thus allowing the incorporation of the model in other modelling processes using a Java Virtual Machine code (.java text file) (Wilenski and Rand, 2015). This modelling environment was identified as an efficient ABM modelling environment mainly because of: usability in different domains; minimised programming effort; extensive documentation and user support; intermediate speed in complex models; and an overall professional appearance (Railsback et al., 2006).

Swarm (Minar et al., 1996) is a kernel and a collection of libraries designed as a general language and toolbox for designing ABMs from all the scientific disciplines. It was developed at the Santa Fe Institute and is now developed by the Swarm Development Group. Swarm simulates collections of interacting agents. The main key concepts of Swarm are the separate modelling and observation features, requiring first to model and then to select what to observe (Railsback, 2006). Swarm is a stable platform suited to hierarchical models that should be considered if the programmer has advanced skills, and if hierarchical models or structure formation are of interest (Berryman, 2008). Swarm has two versions with Java or Objective C programming languages. In order to fully make use of the Swarm libraries it has been suggested to use an Integrated Development Environment (IDE) (Berryman, 2008).

Repast (Collier, 2003) started as a Java implementation of the Swarm tool and expanded. Repast does not implement Swarms and it is mainly addressed to social science's ABMs (Railsback, 2006). It is widely used and has a Python version (RepastPy) and a version for beginners (RepastSymphony). It features many useful tools from displaying, charting, R compatibility, statistical toolkits and many more (Berryman and Kindleman, 2008). Furthermore, it incorporates a built-in simple model, and interfaces with menus and Python code with the objective to make the design of an ABM usable from a beginner in programming (Railsback, 2006).

In this research, Repast and NetLogo were short listed as two tools that could be potentially used for designing and implementing the domestic water demand behaviour model. NetLogo was finally selected mainly because of the available support documents, the support community and the vast amount of freely available models to use and get inspired from. Another advantage of the NetLogo was the ease of use, in particular for a beginner in programming.

3.4.3. Selection of ABM documentation procedure

Agent based models have been criticised as poorly documented and difficult to replicate and thus evaluate (Lorek and Sonnenschein, 1999). Grimm et al., in 2006, created a protocol for documenting ABMs. The purpose of this protocol is to lead to as complete as possible model descriptions that will eventually make ABMs “easier to replicate and hence less easily dismissed as unscientific” (Polhill et al., 2008). This protocol suggests that any ABM documentation should include the model’s overview, design concepts and details. This protocol was named ODD from the first letters of the proposed three descriptive categories. These categories include as well the following:

a. **O**verview contains the outline of the model including the model’s entities, processes and scheduling, allowing the replication of the model, using the following subcategories:

  - Purpose of the model
  - State Variables and Scales that describe the low level variables of the model (those that are not estimated using other variables)
  - Process Overview and Scheduling that describe the entities that undertake each process using the described variables

b. **D**esign concepts does not describe the design of the model per se but provides information regarding the underlying concepts of the model’s design, which are defined by the following subcategories (Polhill et al., 2008):

  - Emergence (a summary of emergent phenomena),
  - Adaptation (whether agents have the ability to adapt their behaviour),
  - Fitness/Objectives (model’s and agents' goals),
  - Prediction (whether agents predict the impact of their decisions),
  - Sensing (whether agents sense in some way their environment),
  - Interactions (agents interact with each other and their environment),
  - Stochasticity,

- Collectives and
- Observation

c. **D**etails should include all the information required for complete re-implementation of the model (Polhill et al., 2008), defined using the following subcategories:

  - Initialisation contains the processes that the model uses in order to start the simulation
  - Input contains the external data used by the model
  - Submodels provide all the details regarding the processes briefly presented in the Process overview and Scheduling section

In this research, it was decided to use the ODD protocol as a roadmap without strictly following the proposed categorisation but providing as much information as possible, relevant to the ODD, for the developed ABM. The ODD protocol was revised in 2013 (Muller et al., 2013) and it was proposed to include a theoretical and empirical background especially for those models that aim at simulating human decision making processes. Nevertheless, for the purposes of this thesis the theoretical and empirical background of the agent based model are presented in a separate chapter (Chapter 2). Additionally, model testing and validation are not part of the ODD protocol (Pollhil et al., 2008) but for the purposes of this research, the developed ABM was both validated and its usability was tested using as a case study, the Athenian urban water system.

3.5. Summary

In this research, an agent based modelling was proposed as a means to simulate the urban household's water demand behaviour. The Urban Water Optioneering Tool was also selected to simulate the evolution of domestic water demand by modelling the frequency of use of household appliances. These two approaches are combined utilising the ability of both tools to capture emerging (bottom-up) behaviour and thus providing the missing link to the modelling of the social dimension of the urban water system for supporting the adaptive urban water management.

The agent based model is proposed to be built using the NetLogo modelling environment, and documented following the guidance of the ODD protocol. Furthermore the use of social research methods is proposed as a means to tackle the unavailability of data and information regarding the attitudes and behaviours of water users towards water use, water conservation and water technologies.

The specific modelling methodology developed in this work, the creation of the ABM, the use of UWOT and their combination is presented in Chapter 4.

Chapter 4. Methodology

"Do or do not, there is no try" - Yoda

4.1. Introduction

This chapter presents the proposed methodology that incorporates the end-user's behaviour in the simulation of the urban water system's evolution. A bottom-up approach is used, acquiring the macro water demand behaviour of the urban water system's social component by modelling the micro water demand behaviour of the urban household. This is achieved by creating an agent based model, the Urban Water Agents' Behaviour (UWAB) explicitly simulating a household's water demand behaviour. UWAB is combined with an existing urban water management simulation tool, the Urban Water Optioneering Tool (UWOT) that simulates the evolution of domestic water demand. The combination of these two modelling tools enables the simulation of the response of the urban water system to changing domestic water demand patterns (Figure 4-1).

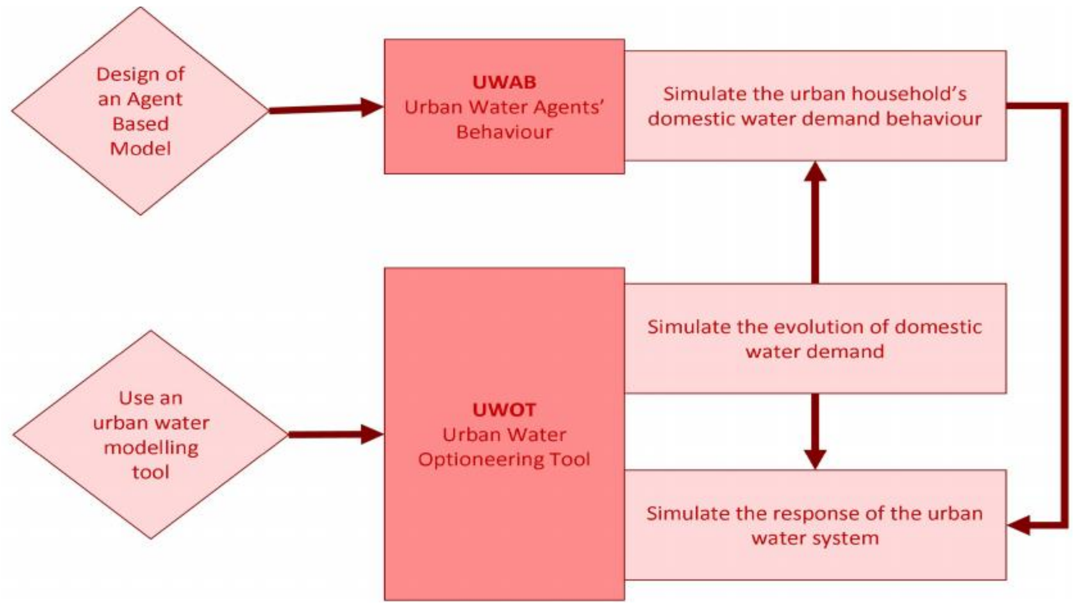


Figure 4-1 Schematic presentation of the proposed methodology

4.2. UWAB model presentation

4.2.1. Purpose

The Urban Water Agents' Behaviour (UWAB) model was designed and developed during this research. UWAB simulates the effects of environmental pressures and water demand management policies on water demand behaviour of households focusing specifically on water conservation. UWAB consists of household agents that are linked together creating a social network. At each time step (here each month) household agents form an attitude towards water conservation shaped by a social impact parameter that is related to the water conservation attitude of their counterparts and to water demand management policies. Every three months, household agents, depending on their attitude and on their water bill decide a level of water conservation (zero, low and high).

Unlike other agent based models that deal with domestic water demand (e.g. Athanasiadis et al., 2005 or Galan et al., 2009) this model does not include a statistical or econometric model of consumption and focuses only on the household's water demand behaviour. Water consumption is then estimated using a model specifically developed to simulate demand from the appliance level all the way to the water source (UWOT – presented in section 4.3). In this section the variables, processes and design concepts of the UWAB model are presented using the ODD protocol (Grimm et al., 2006) in the form of a roadmap, following recommendations by Polhill et al. (2008).

4.2.2. Design concepts

Using the ODD terminology, UWAB's design concepts can be defined as follows:

Emergence: Emergence in UWAB relates to the fact that the micro behaviour of each household agent results in the estimation of the macro behaviour of the community. This behaviour is then converted into water demand through UWOT.

Adaptation: Household agents adapt their behaviour firstly by changing their attitude on water conservation due to the social impact exerted on them. Then, household agents review their decision regarding water demand behaviour based on the effect of their behaviour on their water bills.

Fitness: At an individual agent level, households measure the fitness of their decision by assessing their goal of reducing their water bills. Global 'fitness' is measured after integrating with UWOT and producing results of mean monthly domestic water demand. It is evident that the individual's pursuit of fitness (water bill decrease) does not necessarily lead to a global maximisation of fitness.

Prediction: Household agents anticipate the reduction of their water bill. They have however no memory or learning mechanisms.

Interaction: Household agents interact with each other forming social networks and influencing each other's water conservation attitude. Through the social impact parameter

(I) (see below), household agents interact with their social network and are affected by policy measures.

Sensing: Household agents are assumed to know the water conservation attitudes of their social network and to be informed of the onset of a drought in their region.

Stochasticity: UWAB introduces stochasticity in the selection of the water demand microstate that the household agent decides to be in (see below).

4.2.3. State variables and scales

There are two main categories of variables in UWAB: the experimental and the household agents' variables. The experimental variables are constant throughout the simulation and are used in the sensitivity analysis, validation, calibration and optimisation processes of UWAB. The household agents' variables are intrinsic to each household agent and remain constant throughout the simulation. The household agents' variables follow a distribution that is defined by the experimental variables. Table 4-1 summarises these variables, their bibliographic references. The following paragraphs provide information on the variables and link household agents' variables with experimental variables. The variables' setup and descriptions are given in Annex I categorised per household agent's decision procedure where appropriate.

Table 4-1 Summary of household agents' variables, their bibliographic references and the link to experimental variables

Household agents' variables	References
Age level (a)	Beal et al., 2011b, Campbell et al., 2004, Gilg and Barr, 2006
Income level (i)	Arbues et al, 2003, Kenney et al., 2008, Potter et al, 2010, Beal et al., 2011b, Harlan et al., 2009, Mondejar-Jimenez et al., 2011, Willis et al., 2009, Campbell et al, 2004, Kemmelmeier et al., 2002
Education level (e)	Mondejar-Jimenez et al., 2011, Gilg and Barr, 2006, Campbell et al., 2004, Kemmelmeier et al., 2002, Gregory and Di Leo, 2003, Jones et al., 2011
Household occupancy (ho)	Beal et al., 2011b, Campbell et al., 2009, Willis et al., 2011
Housing type (renting or owning) (ht)	Arbues et al., 2003, Campbell et al., 2004, Randolph et al., 2008, Harlan et al., 2009, Randolph and Troy, 2008
Water demand categories (wd)	Beal et al., 2010, Willis et al., 2011
Difficulty in decreasing water demand (dwd)	
Environmental consciousness (ea)	Mondejar-Jimenez et al., 2011, Gilg and Barr, 2006
Initial positive or negative attitude (O) Link to: Distribution of positive attitudes towards water conservation (%ipa)	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Positive or negative external influence (O_e) Link to: Distribution of the population affected by an external (to the modelled area) source of positive attitudes towards water conservation (%epa)	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Strength of influence (S) Link to: Mean strength of influence (S)	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Strength of external influence (S_e) Link to: Mean strength of influence (S)	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Strength of influence regarding price changes (S_{PC}) Link to: Influence strength of water price changes information (S_{PC})	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Strength of influence regarding awareness raising campaigns (S_{AC}) Link to: Influence strength of water saving awareness campaigns (S_{AC})	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006
Opinion stubbornness (b)	Latane, 1981, Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006

a. Household agents' variables

The low level parameters of the household agents (Grimm et al., 2006) are presented in the next paragraphs and are summarised as follows:

Population characteristics:
1. social-characteristics: age, income level, education level, household occupancy, housing type (renting or owning house)
2. water demand categories (wd)
3. difficulty in decreasing water demand (dwd)
4. environmental consciousness (ea)

Social impact variables:
1. Initial attitude (O)
2. External influence (O_e)
3. Strength of influence (S)
4. Strength of external influence (S_e)
5. Strength of influence regarding price changes (S_{PC})
6. Strength of influence regarding awareness raising campaigns (S_{AC})
7. Opinion stubbornness (b)

The following paragraphs present these household agents variables.

1. **Population characteristics: social-characteristics:** age (a), income level (i), education level (e), household occupancy (ho), housing type (renting or owning house) (ht)

As stated in Chapter 2, water demand is shaped inter alia by social characteristics. Furthermore, social characteristics are important for creating a social network that takes into consideration population's immediacy preferences. Population's social characteristics are typically measured every 10 years during the Censuses performed by most European countries. Other sources of social characteristics data are national statistical services and social institutes that may have available complex indices combining the different social characteristics of the population (i.e. class levels based on education, housing type and income level (NCSR, 2006)). The parameter for family size depicts the actual family size of one, two, three, four or five people living in the household. The remaining variables follow a bipolar scale creating categories of age, income, education and housing conditions. The bipolar scale is used to integrate the effects of each parameter to water demand behaviour. Based on the literature (see Chapter 2), the higher the age, the education and the income level, the higher is the possibility to behave water wise. In addition, households that own their house tend to behave more water wise than households that rent.

2. **Population characteristics: water demand categories (wd)**

These categories refer to the baseline water demand of a household that is mainly linked to the intrinsic motivation and self-determination in the behaviour of the household (see Chapter 2). Thus, the water demand category follows a household-agent throughout the simulation.

3. **Population characteristics: Difficulty in decreasing water demand (dwd)**

It is assumed that high water users are more capable to decrease their water demand since they consume relatively more water and there is a higher chance that they spent more water in recreational uses (e.g. watering the garden, the balcony more times than needed). This is a household-agent personal parameter that tries to capture the effects of other characteristics than those inserted in the model that enable water conservation behaviour. A bipolar scale is assigned to this parameter to integrate the effects of the difficulty in decreasing water demand to the water demand behaviour rule. For that reason low users are assigned a -1 value signifying their higher difficulty in decreasing their water demand, mean users are assigned a zero and high users a + 1 value signifying that it is easier for them to decrease their water demand.

4. Population characteristics: environmental consciousness (ea)

As explained in Chapter 2, people with a strong environmental consciousness tend to conserve more water. Consequently, the model includes a variable that sets the environmental consciousness of the population. This variable follows a bipolar scale from -2 to 2 creating five categories of environmental consciousness ranging from high environmental consciousness to very low environmental consciousness. The bipolar scale is used to integrate the effects of environmental consciousness to water demand behaviour. Based on the literature (Gilg and Barr, 2006), the higher the environmental consciousness the higher the possibility to behave water wise. It is therefore assumed that those household agents that in t=0 have a positive opinion towards water conservation are as well those household agents that have high environmental consciousness. Therefore, UWAB assigns both high environmental consciousness and positive water conservation attitude to the proportion of the household-agent household agents set by the experimental variable by the experimental variable of the initial percentage of positive attitudes (%ipa).

In Chapter 2, the Social Impact Theory was presented. It is possible, yet quite difficult, to acquire such information regarding a specific population sample by running a social quantitative research using questionnaires or social qualitative research using small-group interviews that measure the samples stubbornness and power of influence in water related issues. However, if there is no information available regarding the social influence level in the society, these six variables should be considered experimental variables and their values can be set during the model's calibration process.

Six variables from the social impact equation are personal and are set, in our method, by sampling the distributions created using the respective experimental variables: the initial positive or negative attitude; the positive or negative external influence; the strength of influence; the strength of external influence; the strength of influence regarding price changes; and the strength of influence regarding awareness raising campaigns.

1. Social impact variables: Initial attitude (O)

Every household agent is assigned a positive or negative opinion towards water conservation. The sign of the opinion (positive (+) / negative (-)) is sampled from the distribution created by the experimental variable of the initial percentage of positive attitudes (%ipa).

2. Social impact variables: External influence (O_e)

Every household agent is assigned a positive or negative external influence towards water conservation. The sign of the influence (positive (+) / negative (-)) is sampled from the distribution created by the experimental variable of the percentage of external positive attitudes (%epa).

3. Social impact variables: Strength of influence (S)

4. Social impact variables: Strength of external influence (S_e)

Each household-agent is assigned a value sampled from a normal distribution with a mean value set during the calibration process and a standard deviation set at eighty percent of the value of the mean. Mean strength of influence (S) is set as an experimental variable.

5. Social impact variables: Strength of influence regarding price changes (S_{PC})

Each household-agent is assigned a value sampled from a normal distribution with a mean value set during the calibration process and a standard deviation set at eighty percent of the value of the mean. Mean influence strength of water price changes information (S_{PC}) is set as an experimental variable.

6. Social impact variables: Strength of influence regarding awareness raising campaigns (S_{AC})

Each household-agent is assigned a value sampled from a normal distribution with a mean value set during the calibration process and a standard deviation set at eighty percent of the value of the mean. Mean influence strength of water saving awareness campaigns (SAC) is set as an experimental variable.

In addition there are personal variables that take part in the social impact procedure that are set as constants and are not linked with experimental variables. These are:

7. Social impact variables: $_{\text{Opinion}}$ stubbornness (b)

The opinion stubbornness requires knowledge regarding the society's stubbornness. If it is impossible to find such type of information this parameter could be set to a constant of 2 based on theory (Kacperski and Holyst, 1999, Bahr and Passerini, 1998, Wragg, 2006. Nevertheless, this constant value has not been yet explored in terms of its psychological basis.

b. Experimental variables

The experimental variables remain unchanged throughout the modelling procedure. Household agents use these variable either per se or in order to sample their own personal variable from the distribution created using the selected mean value by the user. These variables are used for UWAB's calibration and optimisation processes. The experimental variables are:

1. Social Network's structure (SN)
2. Distribution of positive attitudes towards water conservation (%ipa)
3. Distribution of the population affected by an external (to the modelled area) source of positive attitudes towards water conservation (%epa)
4. Volatility of Social Impact (T)
5. Mean strength of influence (S)
6. Influence strength of water saving awareness campaigns (SAC)
7. Influence strength of water price changes information (SPC)
8. Total time of transmitting information regarding water pricing changes (M)

A limitation of this work is the need to make assumptions that is tackled mainly by providing at least informed assumptions, supported by sensitivity analysis, uncertainty analysis and calibration. This approach identifies as well the key data sets that really need to be looked for in any new case study. A more detailed description of the population variables is given in the following paragraphs and their setup and summarised descriptions are given in Annex I categorised per household agent's decision procedure where appropriate

1. Social Network's structure (SN)

The interaction between different household agents, influencing their attitude and water demand behaviour, is approached using network theory, as proposed by Sobkowizc (2009). Two complex network structures are available: the small-world structure and the scale-free structure. The selection of either one is dependent on the sensitivity analysis specific to the case study.

2. Distribution of positive attitudes towards water conservation (%ipa)

As explained in Chapter 2, the analysis of the shaping factors of water demand behaviour led to the identification of an entry point towards the decision making process for conserving water: a positive attitude towards water conservation. This entry point is important since a positive attitude does not always lead to an actual water saving behaviour (Dolnicar and Hurlimann, 2010) while it does imply a positive attitude towards water conservation. This population variable is set by assigning constant values derived from a sensitivity analysis specific to the case study.

3. Distribution of the population affected by an external (to the modelled area) source of positive attitudes towards water conservation (%epa)

An external social influence parameter has been added in order to include the effects of the social network of each household that is not included in the area's social network (e.g. friends and family living in other cities or countries but still being able to influence decisions).

4. Volatility of Social Impact (T)

Volatility may be interpreted as "social temperature" that describes a randomness degree in the behaviour of individuals (Kacperski and Holyst, 1999). For more information on the concept of volatility see Chapter 2. In this specific case, the volatility of social impact captures the susceptibility to change of the average attitude in the simulated population (Kacperski and Holyst, 1999, Bahr and Passerini, 1998). Low values of T mean that household agents' attitudes are highly dependent on their social network's attitudes, thus more probable to be affected by the social impact (Ii) exerted to them, whereas higher levels of T reduce the power of Ii in determining a household agent's attitude. (Wragg, 2006).

5. Mean strength of influence (S)

In UWAB the mean strength of influence is an experimental variable that is used to create the distribution of the strength of influence in the household-agent population. More information regarding the Social Impact Theory can be found in Chapter 2.

6. Influence strength of water saving awareness campaigns (SAC)

7. Influence strength of water price changes information (SPC)

Designing the UWAB model it was assumed that the effect of the water saving awareness campaigns and of pricing policies is related to the influence strength of the media that transmits the relevant information. It is acknowledged that a campaign may run on different media such as TV, radio, internet and may also use other forms of information transmission such as leaflets in the water bill, posters in city's central points etc. This global variable is presumed to incorporate the mean strength of influence of all those means of transmission. The household agent will use the created distribution for sampling the value of his intrinsic influence for each one of these two water demand management policies.

8. Total time of transmitting information regarding water pricing changes (M)

Months before and after, a water price change event, that the information regarding the price change is transmitted. This population variable tries to acknowledge and incorporate in the model the effect of information transmission regarding price changes. Water companies, authorities and media may chose to alert the public, to influence their behaviour, before actually implementing the price changes. Furthermore, the public may be reminded "that water prices were increased/decreased" for political and/or water demand management purposes. This information is difficult to be retrieved for historical events and is affecting the household agent's behaviour (see 7.7.8) therefore the variable is an experimental variable.

4.2.4. Process overview and scheduling

Household agents are assumed to think about (and revise) at regular intervals (here every three months, corresponding to the billing frequency in Athens) their attitude towards water conservation (positive or negative) and decide about their water demand behaviour, selecting one out of three (idealised) water conservation "levels" (zero, low or high conservation).

Household agents' attitudes towards water conservation are influenced by their social network and external factors, such as water policies including water price changes and awareness raising campaigns. The interaction between different household agents, influencing their attitude and water demand behaviour, is approached using network theory, as proposed by Sobkowizc (2009). To form the network, household agents are linked to each other randomly. The network is expanded by using the sum of the difference of the socio-demographic characteristics of the paired household agents as a proxy to the strength of the social links thus allowing for the simulation of the effects of social immediacy (Sobkowizc, 2009).

Household agents with a negative attitude towards water conservation can only select the "zero" water conservation level for their water demand behaviour state. On the other hand, household agents with a positive attitude towards water conservation may choose one out of all three water conservation levels (zero, low or high conservation). Household agents' receive, every three months, water bills. The household agents compare their current water bill with their previous one and decide whether they prefer a higher, lower or the same level of conservation for their water demand behaviour state. This preference is used by the household agents in their water demand behaviour decision procedure. The procedures followed by the household agents are shown in Figure 4-2 and explained in the following section.

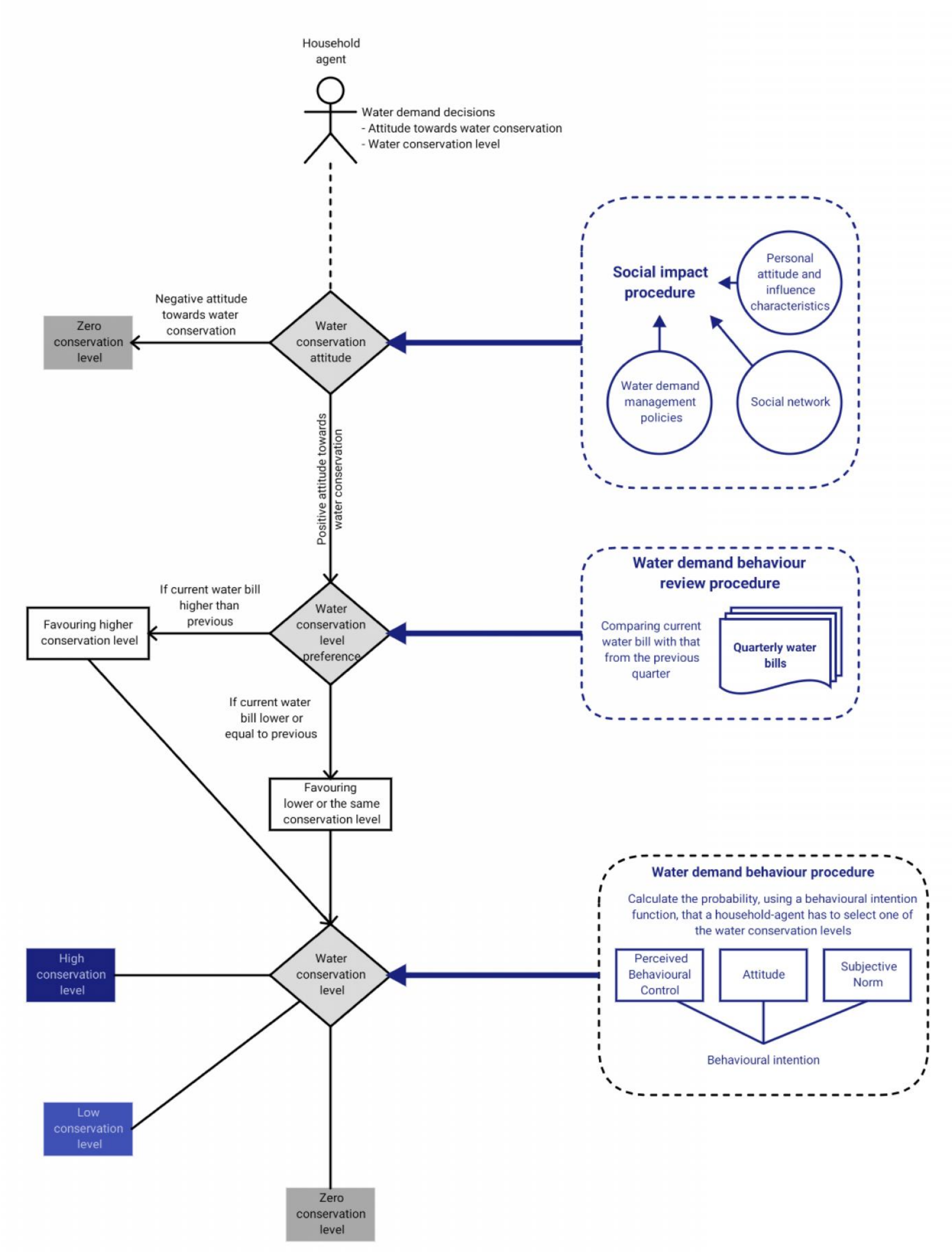


Figure 4-2 Household agents' procedures

4.2.5. Submodels

UWAB utilises three key submodels: the social impact procedure, the water demand behaviour procedure and the water demand behaviour review procedure.

a. Social impact procedure

During this procedure, the household agent's water conservation attitude is affected by their own social network and external water policies. This effect (termed Social Impact, I) is estimated using the Social Impact Theory (see Chapter 2) Each household agent uses Equation 4-1 to calculate the social impact (I_i) exerted to them by (a) each household agent's social network and (b) by water demand management policies currently in effect.

$$I_i = -S_i b - O_i h - \sum_{i,j=1}^{n} \frac{S_j O_j O_i}{d_{i,j}^{\ 2}}$$

Equation 4-1

where,

I_i is the exerted social impact on household agent i who is a member of a social network of n other agents (j).

O_i (positive or negative) is the household agent's attitude on water conservation (-1 or +1)

S_i is the household agent's strength of influence (>= 0)

b is the household agent's stubbornness (= 2)

h is the external influence $h = S_{PC} O_{PC} + S_{AC} O_{AC}$ where,

S_{PC} is the strength of influence regarding water price changes information (>= 0),

O_{PC} is the information regarding water price changes (if water prices increase, then OPC is positive if prices decrease then OPC is negative (-1 or +1), creating a positive or negative influence towards water conservation respectively)

S_{AC} is the strength of influence regarding awareness raising campaigns (>= 0) with a value of zero corresponding to an absence of awareness raising campaigns

O_{AC} is the awareness campaign's attitude which is always positive.

The term ($\sum_{i,j=1}^{n} \frac{S_j O_j O_i}{d_{i,j}^{\ 2}}$) is the influence of the social network of the household agent i that includes n other household agents j with each member of the social network having a strength of influence S_j, an attitude O_j and a social distance d_{ij}.

Social distance (d_{ij}) measures the ease of communication between two individuals within a given population and is assumed to be related to the proximity of an agent's socio-demographic characteristics to those of her peers. The magnitude of mutual interactions decreases with distance. The social distance is calculated by summing the differences of the social characteristics of the two linked household agents. If two linked agents have the same socio-demographic characteristics they exert to each other the highest possible impact. They have however a social distance of 0 thus a value of one is added to the social distance equation as depicted in Equation 4-2:

$$d_{ij} = 1 + \left| \sum_{i,j,n=1}^{n} x_{n_i} - x_{n_j} \right| \qquad \text{Equation 4-2}$$

where,

dij is the social distance between the two linked household agents i and j

$X_{ni,j}$ is the social characteristics of the two linked household agents i and j with x equal to the household agent's variables for age (a), income level (i), education level (e), household occupancy (ho), housing type (renting or owning house) (ht).

Household agents run this procedure every three months and their attitude remains unchanged for the following three months. The probability that a particular agent i will change her attitude due to social impact I_i is calculated using Equation 4-3. This is based on the notion of "volatility" of social impact, introduced by Bahr and Passerini (1998), as a measure of an individual's susceptibility to change, amended by Kacperski and Holyst (1999) to include a degree of randomness in the (otherwise deterministic) pressure.

$$P_{change} = \frac{\exp\left(\frac{I_i}{T}\right)}{\exp\left(\frac{-I_i}{T}\right) + \exp\left(\frac{I_i}{T}\right)}$$

$$\begin{aligned} &\text{if } X < P_{change} \Rightarrow O_i(t+1) = -O_i(t) \\ &\text{if } X > P_{change} \Rightarrow O_i(t+1) = O_i(t) \end{aligned} \qquad \text{Equation 4-3}$$

where,

P_{change} is the probability of an individual changing their attitude

I_i is the exerted social impact

X is a randomly selected number from a uniform distribution of [0,1]

$O_i(t)$ is the attitude of the household agent i during the quarter t

T is the average volatility or social temperature of social impact. Low values of T mean that household agents' attitudes are highly dependent on their social network's attitudes, thus more probable to be affected by the social impact (I_i) exerted to them, whereas higher levels of T reduce the power of Ii in determining a household agent's attitude.

The result of the overall procedure is either a positive or a negative attitude towards water conservation of household agent i for the next three months of the simulation.

b. Water demand behaviour procedure

It is understood that a positive attitude towards water conservation (such as the one derived from the social impact procedure above) does not necessarily lead to an actual water saving behaviour (Dolnicar and Hurlimann, 2010). It only increases the chances of such a behaviour actually taking place. Based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) (see Chapter 2) the attitudes and the subjective norms are supplemented by the perceived behavioural control and all together act upon the behavioural intention to consume water in a certain manner. The stronger the intention the more likely is the behaviour to be performed (Ajzen, 1991).

In the context of this work, a qualitative socio-psychological research was undertaken during 2013, working with a panel of Athenian water users. The results of this study helped the identification of the shaping factors of domestic water demand behaviour. The most significant factors were identified as the effects of awareness raising campaigns, one's intrinsic environmental consciousness, the end-user's socio-economic level and the expected outcome that water conservation could have on the water bill (Gerakopoulou, 2013). Based on these results as well as on an extensive literature review, a number of key factors affecting water demand behaviour were identified and are presented in Figure 4-3 and explained in the following paragraphs.

Behavioural Intention = Attitude + Subjective Norm + Perceived Behavioural Control

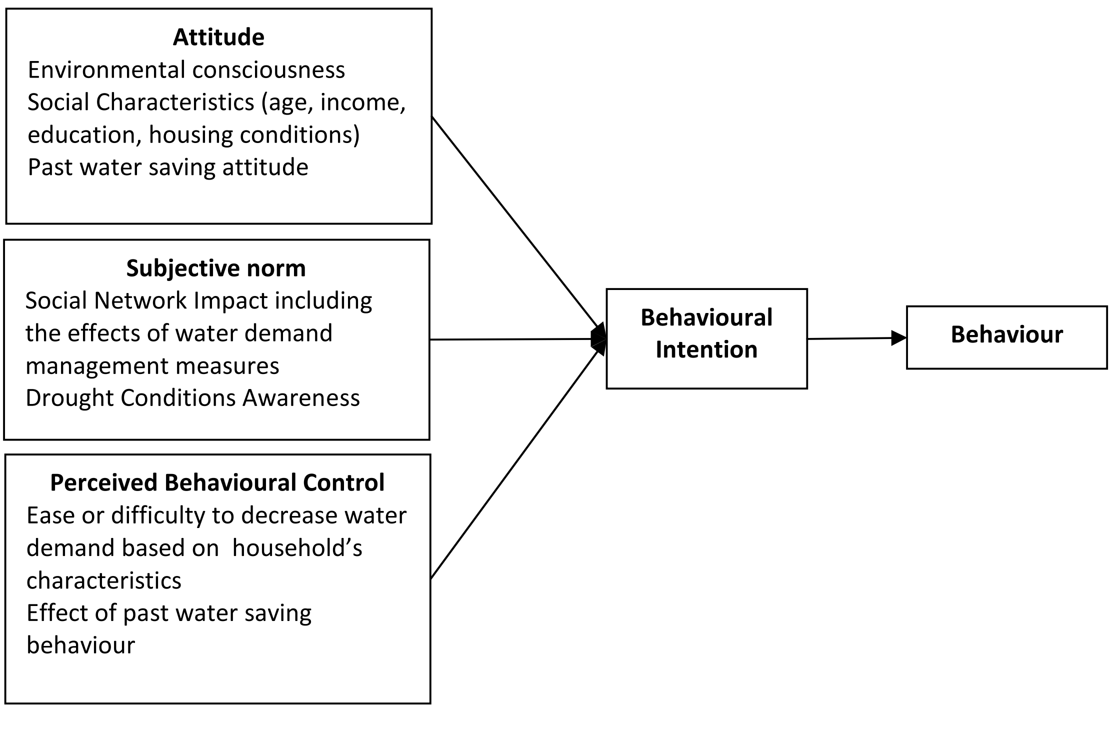


Figure 4-3 Factors influencing actual water demand behaviour

Attitude relates to a favourable (or unfavourable) evaluation of the behaviour in question (Ajzen, 1991). Water users' conservation attitude relates to a number of socio-demographic factors such as: residents' age, income level, family size, education level and household characteristics (size, age, type of domestic water technologies configuration) (Arbués et al., 2003, Barrett, 2004, Beal et al., 2010, Campbell et al., 2004, Fontdecaba et al., 2011, Harlan et al., 2009, Jones et al., 2011, Mondejar-Jimenez et al., 2011, Randolph and Troy, 2008, Willis et al., 2011). In addition, household's water conservation attitude is linked to water users' environmental attitude (Gilg and Barr, 2006), the weather (Baki et al., 2012, Koutiva et al., 2012) and past water saving behaviour (Gerakopoulou, 2013).

Attitude = Environmental Consciousness + Social Characteristics (age, income, education, housing conditions) + Past water saving attitude

Subjective norm towards the behaviour to conserve water is the perceived social pressure towards that behaviour (Ajzen, 1991). Perceived social pressure can be attributed to the impact of the social network and the effects of water demand management measures such as awareness campaigns (Gregory and Di Leo, 2003) and water prices changes (Jorgensen et al., 2009).

Subjective Norm = Social Network Impact (including public policies effect) + Drought Condition Awareness

Perceived behavioural control over the decision to conserve water is the ease or difficulty to perform a certain behaviour as perceived by the individual (Ajzen, 1991). The effect of the policy measure of water use restrictions is included in this term of the behavioural intention function. A household that is required to follow water restrictions increases the perceived behavioural control over water conservation because it is requested to follow a certain water conservation behaviour (Cooper et al., 2011). This requirement increases the individual's perception about the extent of their capacity to achieve a behaviour (water conservation) in a successful way (d'Astous et al. 2005) irrelevant to the household's own water conservation attitude. The perceived behavioural control is linked to the household's characteristics that affect its water demand and is represented by a variable which is linked to the level of water demand of the household. This parameter is also backed up by literature that suggests that the amount of required effort for performing a behaviour is strongly linked to the decrease of the relationship between attitude and behaviour (Bagozzi et al., 1990).

Perceived Behavioural Control = Ease or difficulty to decrease water demand + Effect of past water saving behaviour + Restrictions effect

Therefore:

Behavioural Intention (BI) = Environmental Consciousness (ea) + age (a) + income (i) + education (e) + housing type (ht) + Past water saving behaviour (p) + Social Network

Impact (s) + Drought Condition Awareness (d) + Ease or difficulty to decrease water demand (dwd) + Effect of past water saving behaviour (f) + Restrictions effect (r)

In this research, three discrete microstates of water conservation, low, high and no conservation are been assessed. Household agents use the following rule to calculate their behavioural intention for each one of the three microstates based on their intrinsic characteristics, the water demand management policies in place, weather conditions and their past water demand behaviour.

Behavioural intention of high conservation (BIHC) = ea + a + i + e +ht + p +s + d + dwd + f + r

Behavioural intention of low conservation (BILC) = ea + a + i + e + ht + p + s + d + dwd + f + r

Behavioural Intention of no conservation (BINC) = s - (ea + a + i + e + ht + p + d + dwd + f)

The factors presented above were used to create the behavioural intention functions that household agents use for each one of the three possible discrete states of water demand behaviour with low (BILC), high (BIHC) and zero (BINC) water conservation level. As suggested above, every household agent estimates its behavioural intention every three months. The values of the behavioural intention's components have been selected in a way that the higher behaviour intention would correspond to a higher probability for water conservation (values of the variables are given in Annex I).

The behavioural intention of each water demand behaviour state is regarded as the "energy" of each state and every household agent as a "thermodynamic system", represented by a canonical ensemble of water demand behaviour states. Therefore, the probabilities of adopting each one of these states are estimated following Equation 4-4.

$$P_{low\ conservation} = \frac{\exp(BILC)}{Z}$$

$$P_{high\ conservation} = \frac{\exp(BIHC)}{Z}$$

$$P_{no\ conservation} = \frac{\exp(BINC)}{Z}$$

Equation 4-4

Where,

$P_{low\ conservation}$ is the probability of the household agent adopting a state of water demand behaviour with low conservation level

$P_{high\ conservation}$ is the probability of the household agent adopting a state of water demand behaviour with high conservation level

$P_{no\ conservation}$ is the probability of the household agent adopting a state of water demand behaviour with zero conservation level

Z is the partition function that provides a normalization factor for the probability distribution: Z = exp(BILC) + exp(BIHC) + exp(BINC)

In order for the household agent to select one of the states of water demand behaviour a number between 0 and 1 is randomly selected. The state whose probability is more than or equal to the random number is then selected by the household agent.

c. Water demand behaviour review procedure

As suggested earlier, each household agent is assumed to receive every three months a water bill. The water bills are calculated outside the UWAB model, incorporating water pricing policies, and are inserted as external information to the model. The household agent compares the current water bill with the previous one and decides whether it is more favourable to change its water demand behaviour state or not. To this effect the model includes a variable in the estimation of the behavioural intention function of the water demand behaviour states with low and high water conservation levels. Depending on the water demand behaviour state of the household agent, the agent shows preference towards the same, lower or higher water conservation levels. For example, if an agent with low water conservation receives a higher water bill than that of the previous quarter then the household agent shows preference to the higher water conservation level (expecting a decrease to her water bill in the next quarter). The effect of the assessment of water bills is depicted in the variable effect of past water saving behaviour (f) that is included in the behavioural intention function.

4.2.6. Initialisation

The UWAB is initialised by creating the population of household agents and their social network. Household agents are assigned their descriptive characteristics (socio-demographics, household type, water user types etc) by sampling the distribution function of these attributes to the actual urban population. Finally, attitudes towards water conservation and water demand behaviour states are randomly assigned to the household agent population.

4.2.7. Input

UWAB requires the import of the different household agent water user and household types and water demand behaviour states.

At the end of each time step the UWAB model calculates the number of household agents that have selected each water demand behaviour state (Figure 4-4).

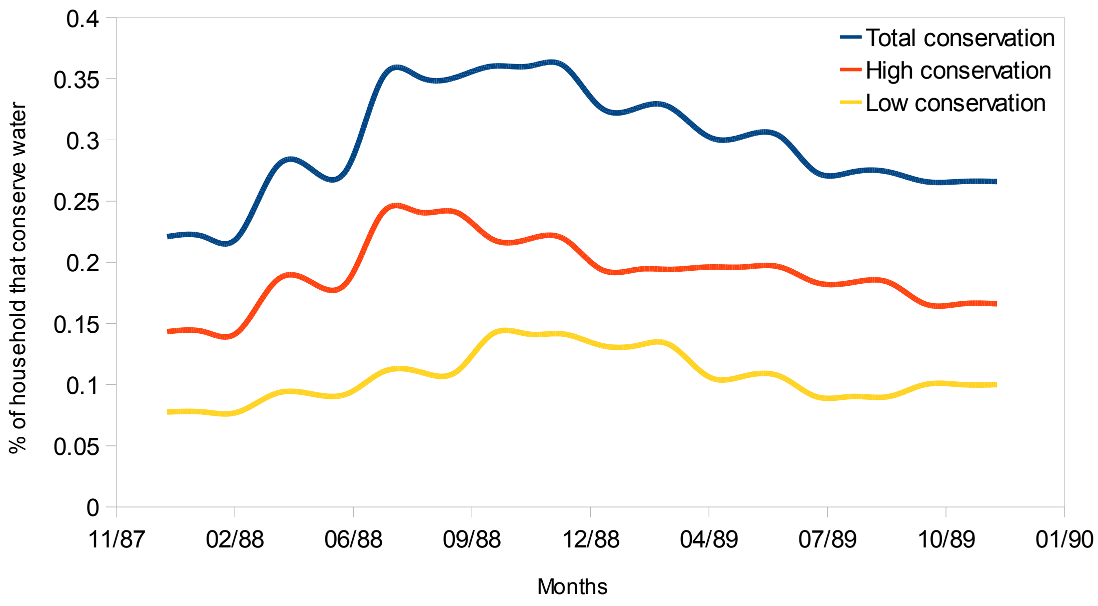


Figure 4-4 Example of UWAB's results

4.3. UWOT

The Urban Water Optioneering Tool is an urban water cycle model that utilises a bottom up approach, simulating water demand generated by household appliances, aggregating those at the household, neighbourhood and city levels and then routing this demand all the way to the water sources (Rozos and Makropoulos, 2012). UWOT is used in this work in a twofold manner: (a) to translate water demand behaviour (represented here by the frequency of use of individual household appliances that use water, such as toilets, washing machines, and showers) into domestic water demand and (b) to simulate the response of the hydrosystem.

4.3.1. Setup of household water demand types

UWOT is used to simulate the evolution in time of the domestic water demand of the different types of water users. Thus only the lower level of the UWOT model is used, which utilises the in-house household water appliances (e.g. toilets, washing machines, shower heads, outside uses etc) to estimate the domestic water demand.

In order for UWOT to simulate the evolution of domestic water demand for the different water demand types it requires the identification of the frequency of use for the different in-house water appliances. These frequencies of use need to incorporate all the conditions relevant to the case under investigation, which are: the distribution of water demand types; the distribution of household occupancy; the selection of annual and monthly water demand trends; and the identification of water conservation levels and dependent changes to the frequencies of use.

The following paragraphs describe the proposed methodology that leads to the assignment of in-house water appliances' frequency of use per water demand type.

a. Setup of distribution of water demand categories

In order to set a reasonable mean water demand for the three water demand categories average, low and high water users it is necessary to have information regarding the distribution of water demand in the urban population under investigation. If such information is unavailable it is possible to use the minimum water demand, usually established by water companies as a minimum billed quantity, and the baseline mean water demand, usually provided by statistical offices. This method, however, will only provide a mean value for the average user category. The estimation of the mean water demand for the low and high water users requires either the actual data of water demand, to calculate distribution statistics and identify the low and high users' water demand or the assumption that the water demand distribution to the population is normal. Expert knowledge suggests that actual water demand is best described by a distribution with a long tail towards higher users (Butler and Memon, 2006). However, for the purposes of this methodology the assumption that water demand is normally distributed allows the estimation of low and high water users' water demand, exploiting the special characteristics of the normal distribution. As a result, if there are no adequate data, the low and high users' water demand is estimated by calculating the centres of mass of the normal distribution and the selected number of standard deviations that marks the lower and higher water users' areas.

b. Setup of distribution of occupancy types

In order to estimate the household's water demand it is essential to have the distribution of occupancy types in the population. Such information is usually available through the National Statistical Offices and the censuses they publish every 10 years.

c. Setup of annual and seasonal water demand trends

Domestic water demand presents seasonal and annual trends. Seasonal trends are usually attributed to weather changes, while annual trends are attributed to the quality of life change in the under investigation community. Usually this kind of information is reported by water utility companies (i.e. EYDAP, 2009). Nevertheless if this type of information is not available it is possible to estimate both trends by total monthly domestic water demand values for seasonal trends and total annual domestic water demand values for annual trends.

d. Setup of frequency-of-use variables for in-house water appliances

UWOT uses frequency-of-use variables for in-house water appliances in order to estimate the water demand of the household. As stated in Chapter 3, UWOT's library for in-house appliances includes all those, that are usually found in a common household of the developed world i.e. hand basins, toilets, shower heads, washing machines etc and includes also a variety of new in-house technologies such as rainwater harvesting and grey water recycling technologies. In order to select the appliances of a common household of the area under investigation, one may look into the reports of the National Statistical Offices and

EUROSTAT relevant to the population's quality of life. Such reports contain the percentage of the population of a city or country that is using certain water related in-house appliances. For acquiring more focused information it is possible to run a small questionnaire based social research asking people within the area of interest about the water infrastructure of their house.

UWOT's parameterisation requires the identification of the household's appliances and the estimation of the frequency of use of the different household appliances for the different water user types. In the absence of such available information it is possible to use appliances' frequencies of use based on scientific literature (i.e. Rozos and Makropoulos, 2013, Beal et al., 2013, Grant, 2006). The appliances' frequencies of use must embed annual and seasonal trends. Seasonal variability is estimated by changing the frequency of use of appliances that are affected by weather changes which are the shower, the washing machine and the outside uses (Rozos and Makropoulos, 2013). The annual trend, however, needs to be incorporated in all in-house water appliances in order to capture the effects of a changing quality of life (assuming that as quality of life increases so is the use of the water appliances).

Assigning frequency of uses for different conservation levels may be challenging. The different water uses of a household may be divided into two separate categories: those for covering everyday basic needs (or non-discretional) and those for covering discretional uses (Willis et al. 2011). Basic needs include water uses related to drinking water, sanitation (flushing toilets), bathing (using the hand basin, shower, bath, washing machine) and kitchen activities (kitchen sink and the dishwasher). Discretionary needs cover additional non-essential water uses, such as irrigation and outdoor activities. On the other hand, the shift towards non-materialistic needs (Inglehart, 2008) has made many basic water needs to include a large discretionary component, such as showering or bathing for relaxing and not for sanitation purposes (Willis et al., 2011). Consequently when exploring the water saving potential of a household, one may also include basic needs to those where water saving is feasible.

However, the assumption, that for conservation purposes certain water uses, even discretionary, are eliminated, is considered extreme and is possibly achieved only by imposing strict measures such as prohibitions on outdoor use and others. Consequently, it is possible to identify the frequencies of use for appliances for both common and decreased water demand by undertaking a questionnaire based social research asking people how often certain appliances are being used in their households and how much they are willing to decrease this use in order to conserve water.

4.3.2. Simulation of domestic water demand evolution

Following the setup of household water demand types in UWOT, the model is able to simulate the domestic water demand evolution for the different water demand types and the different water demand behaviour state.

4.4. Linking UWAB with UWOT

UWOT is setup and run to calculate initial demands and therefore create water billing information. This information is inserted in UWAB which then simulates the evolution of the selection of water demand behaviour states by the household agents. At the end of the UWAB simulation two types of results are available: UWOT results in the form of water demand time series per household type, water user type and water demand behaviour state (Table 4-2) and UWAB results in the form of number of households time series per household type, water user type and water demand behaviour state (Table 4-3).

Table 4-2 UWOT results

Households with 1-5 occupants		Water Demand Behaviour State (c)		
		Low conservation	High conservation	Zero conservation
Water User Type (wu)	Average water user	9 monthly water demand time series in litres per household per day for households with 1, 2, 3, 4 and 5 occupants (a total of 45 time series)		
	Low water user			
	High water user			

Table 4-3 UWAB results

Households with 1-5 occupants		Water Demand Behaviour State (c)		
		Low conservation	High conservation	Zero conservation
Water User Type (wu)	Average water user	9 monthly time series with the number of the total household agents that have selected each water demand behaviour state for households with 1, 2, 3, 4 and 5 occupants (a total of 45 time series)		
	Low water user			
	High water user			

The 45 time series resulted from UWOT are multiplied with the 45 time series resulted from UWAB and the result is multiplied as well with the number of actual households that each household agent represents in order to produce the total monthly domestic water demand. The following Figure 4-5 presents a flow chart of the integration of the UWAB and UWOT models to investigate the evolution of domestic water demand in an urban area.

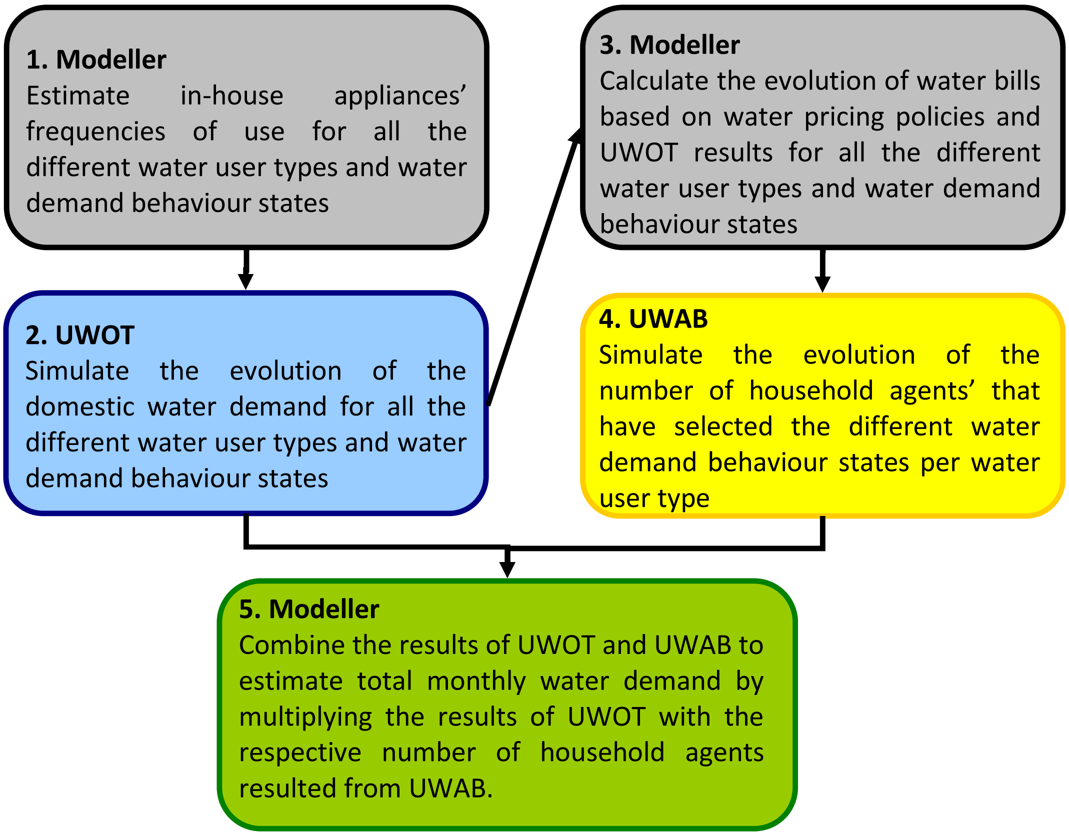


Figure 4-5 Flow chart of the UWAB – UWOT interaction

4.4.1. Validation of the UWAB – UWOT modelling platform

As proposed by Nikolic et al. (2012), Latin hypercube sampling is used to sample the multidimensional parameter space and create experiments for exploring the sensitivity of the proposed model's parameters. One hundred parameter sets are selected and corresponding experiments are created. Latin hypercube sampling is usually performed using a very large number of parameter sets since the number of samples is used for dividing the range of each variable into as many intervals of equal probability as the sample size (Helton and Davis, 2003). Nevertheless, computational burden especially in the case of ABMs tends to identify the efficiency of a large sample (Nikolic et al., 2013). These experiments are repeated as many times as required to decrease the influence of outliers to the average result. The variability of the outcome may be checked by performing 1000 repetitions of one parameter set and checking the statistics of the outcome (standard deviation, skeweness and kurtosis) that could conclude whether or not there is a high variation of the model's outcomes. The higher the variation the more repetitions are needed for acquiring mean values of the results. The mean output of the repetitions of each of the one hundred sampled parameter sets is used for the sensitivity analysis of the proposed modelling platform.

The main purpose of the proposed model validation is to show that the model follows the oscillations of the real world observations and that the model is able to capture these oscillations while water policies are in place. Consequently, two objective functions are used, the first one being the Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970), as it was modified by Krause et al. (2005) and Herrera et al. (2010) (Equation 4-5). The range of the modified Nash – Sutcliffe coefficient lies between 0 (perfect fit) and +∞. Values of more than one signify that the mean (median) value of the historical time series is a better predictor than the proposed model. In addition, a second objective function, the Mean Absolute Percentage Error (MAPE) (Equation 4-6), is proposed for measuring the divergence of the modelled results with the historical values in specific simulation periods were policies are in place.

$$NS\,modified\,(pars_k) = \frac{\sum_{simulation\,start}^{simulation\,end} \left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}}\right)^2}{\sum_{simulation\,start}^{simulation\,end} \left(\frac{E_{WD_i} - \overline{E}_{WD_i}}{\overline{E}_{WD_i}}\right)^2} \qquad \text{Equation 4-5}$$

$$MAPE\,(pars_k) = \frac{\left|\sum_{January}^{December} \left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}}\right)\right|}{\text{total number of months}} \qquad \text{Equation 4-6}$$

where,

k denotes the parameter set under investigation (≥ 0)

i denotes the result of the i-th simulation month

j denotes the monthly interval that calculates as well the total number of months (e.g. j = months 12 to 30, total number of months = 18)

M_{WDi} corresponds to the model's results for the i-th month,

E_{WDi} corresponds to the historical water demand for that i-th month

$\overline{E}_{WD_i}$ corresponds to the mean historical water demand for that i-th month and

parsk corresponds to the respective k-th parameter set, as selected from the Latin hypercube sampling process.

a. Sensitivity analysis

It is proposed to use the Monte Carlo Analysis Toolbox (Wagener, 2004) in combination with the above selected objective functions for the model's experimental variables sensitivity analysis. More specifically it is suggested to use identifiability plots to show the importance of every experimental variable and the possibility to identify one value or a small range of values where the modelling platform's results fit best the historical values. In addition, it is suggested to use the Global Likelihood Uncertainty Estimation (GLUE) plot adopted from (Beven and Binley, 1992) in which, for each time step, the output calculated with a specific parameter set is weighted by the likelihood of the same parameter set. For each point in time, a cumulative frequency distribution is generated using the selected objective function (converted to likelihood by normalizing it) and the confidence intervals are calculated using linear interpolation (Wagener and Kollat, 2007).

b. Modelling platform calibration

The sensitivity analysis leads to the selection of value ranges for the experimental variables to be included in the multi-objective calibration process.

The optimisation procedure is proposed to be implemented using a multi-objective genetic algorithm. Multi-objective genetic algorithm is a method inspired by natural selection and is part of the so-called Evolutionary Optimisation (EO) algorithms. EO algorithms use a population based approach in which more than one solution participates in a single iteration and evolves into a new population of solutions. Multi-objective problems require the selection of a Pareto-optimal solutions' set. EO does exactly that, in a single multi-objective run finds many non-dominated solutions that present trade-offs among objectives (strong in some and weak in others) (Deb, 2001). The aim of the algorithm will be to minimise the two objective functions used in the sensitivity analysis: the Nash-Sutcliffe modified coefficient and the mean absolute percentage error.

The multi-objective genetic algorithm runs for 10, 30, 70 and 100 iterations. Each iteration includes ten different parameter sets and therefore, UWAB runs for 100, 300, 700 and 1000 times respectively. Each iteration set results in a Pareto front which constitutes the calibrated experimental variables. The modelling platform is then initialised based on the results of the optimisation process and run as many times needed to decrease the outlier effect.

4.5. Summary

In this chapter we presented the design of an agent based model able to simulate domestic water demand behaviour and assess the effects of alternative water demand management strategies on that behaviour. We also proposed a methodology for using the Urban Water Optioneering Tool to simulate the evolution of domestic water demand and developed a process for combining the results of the two models. The Chapter also described a specific calibration and optimisation process suitable for these models. The proposed methodology is universal and can be used to support any water resources decision maker. It was developed specifically to be easily transferable to the specific conditions of different case studies.

Chapter 5 presents the software developed to implement the proposed methodology.

Chapter 5. Software

5.1. Introduction

This Chapter presents the software that was developed to implement the proposed methodology. The Urban Water Agents' Behaviour (UWAB) agent based model was developed using the NetLogo agent programming language. UWAB's results are combined with the results of UWOT using a JavaVM code for running UWAB headless and Matlab for combining the results, validating, calibrating and testing the usability of the proposed modelling platform (Figure 5.1).

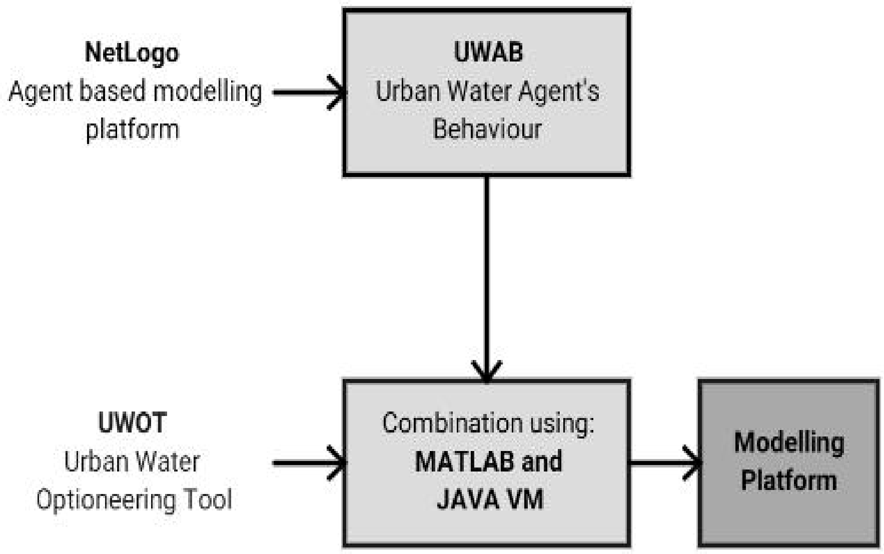


Figure 5-1 Diagram of the different software tools and their combination that create a modelling platform for supporting the adaptive urban water management

5.2. UWAB NetLogo model

The UWAB model was created using the NetLogo version 5.0.3 (Wilensky, 1999) agent programming language. The interface of the model (Figure 5-2) shows the eight experimental variables, which are set as global variables through the NetLogo interface. The following paragraphs present the procedures created in the NetLogo environment to develop UWAB.

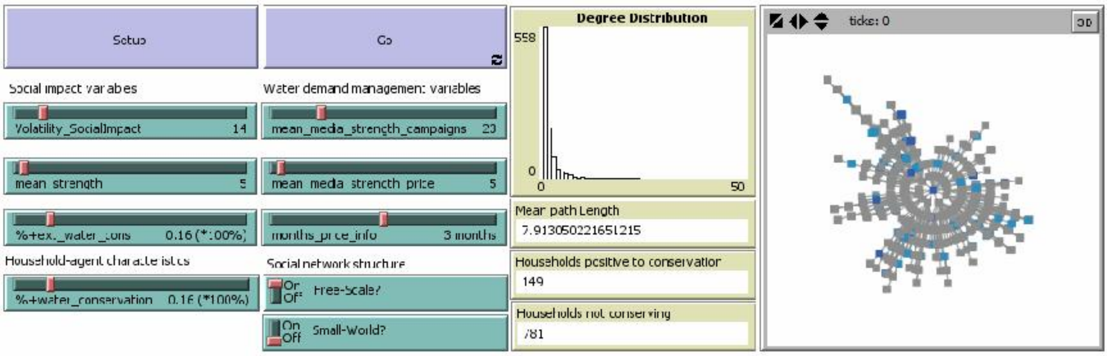


Figure 5-2 UWAB model interface

The model's initialisation process, or setup procedure, initiates the household agents and their environment for time t = 0, ready to begin the simulation. The setup procedure of the model is divided into three processes: (1) the setup of parameters using NetLogo code, (2) the setup of experimental variables using NetLogo interface and (3) the model's setup procedure.

The setup using the NetLogo coding environment is used for setting up those parameters that do not need to change during the experimentation and optimisation process (household agents' social characteristics and model's constant parameters). In addition, the setup of parameters using the NetLogo coding environment may be used, rather than importing the information using CSV files, like for instance in the case of the water demand management procedures.

The experimental variables are set by the modeller, using the model's sliders (see Figure 5-2). These variables are used to design experiments by altering them and exploring their effects on the model's results during the model's sensitivity analysis. It is possible to do this either externally by invoking and controlling NetLogo by another program running on the Java Virtual Machine[2] or by using the BehaviorSpace, a NetLogo tool that enables experimentation with variable values [3].

Figure 5-3 presents a Unified Modelling Language (UML) sequence diagram of all the procedures that take place during the setup and the run procedures of the UWAB model. The following paragraphs describe one by one these procedures.

[2] for more information visit https://github.com/NetLogo/NetLogo/wiki /Controlling-API

[3] for more information visit http://ccl.northwestern.edu/netlogo/docs/

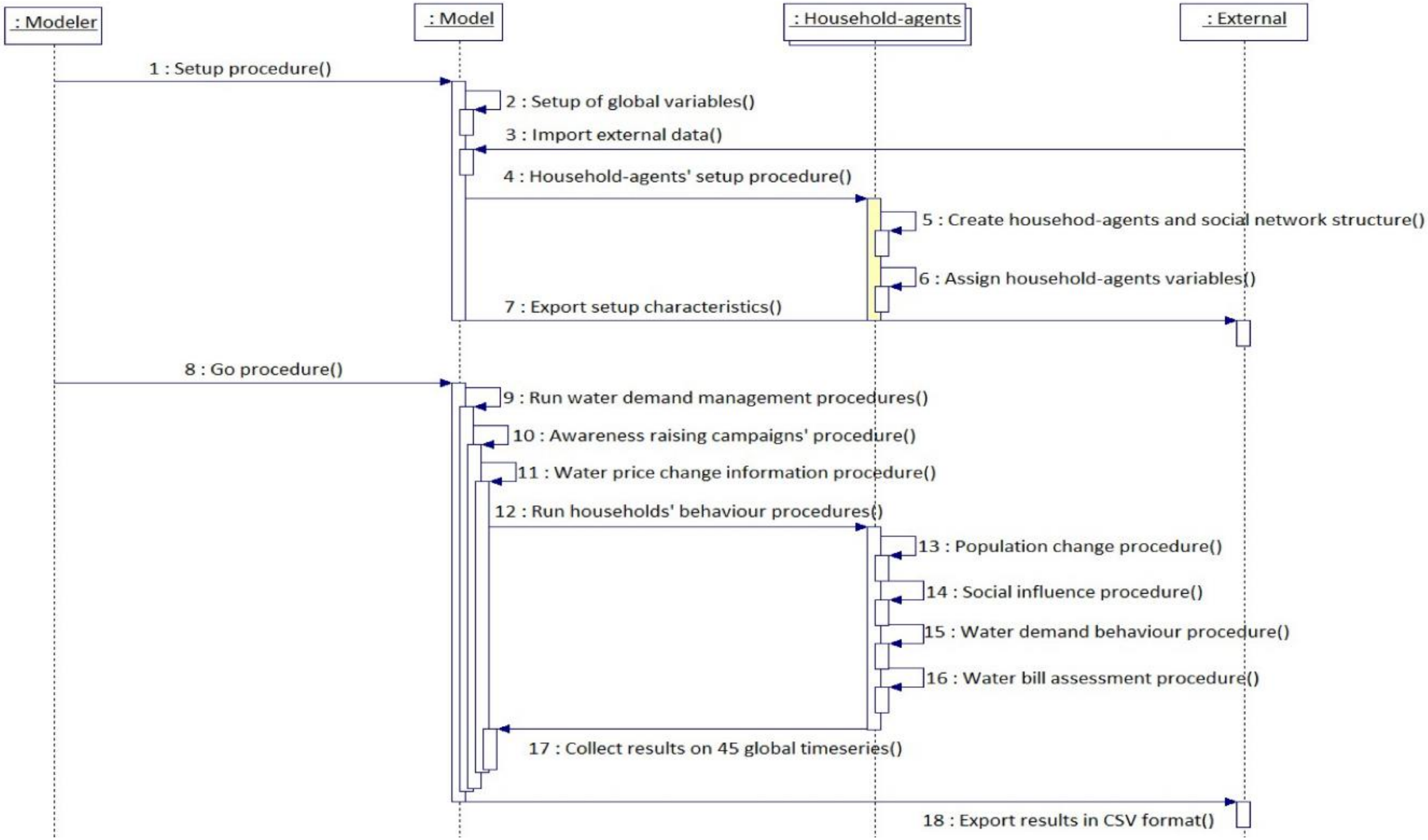


Figure 5-3 UML sequence diagram of UWAB's procedures

5.2.1. Model's setup procedure

The model's setup procedure starts by pressing the Setup button (see Figure 5-2). UWAB uses a series of commands to create the household agents and the environment within which they behave (also termed "turtles" and "world" in NetLogo's own terminology).

The main aim of the setup procedure is to initiate the agents and their environment at t = 0, ready to begin the simulation. For this purpose, the following commands have been coded: the setup of global variables procedure that initialises several global variables and also performs error checking routines needed for the model to begin; the import procedure that imports external information such as the water billing information; the population setup procedures; and the export command, that exports the model's experimental variables values for referencing purposes.

The following paragraphs describe the two commands that are included within the population setup procedure and are used to setup the household agents' variables and set the initial conditions for the commands that the household agents will follow during the simulation process.

a. Create network structure command

The type of the social network structure of the household agents is selected from UWAB's interface. The model includes two options of social network structure, the scale-free network structure (Albert et al., 1999) and the small world structure (Watts and Strogatz, 1998). The scale-free network structure creates hubs of connected entities following the rules of preferential attachment (Albert et al., 1999). The small-world network structure creates one connected component with each entity having at least k neighbours leaving no isolated entities (Watts and Strogatz, 1998).

Depending on the selected network structure UWAB creates the household agents and their social network using, one of two existing sample NetLogo models. The social network is created by following either the Network Sample Model: Preferential Attachment (Wilenski, 2005) for the scale-free network structure or the Network Sample Model: Small-World (Wilenski, 2005) for the small-world network structure. The code of these two models is included in UWAB. These two models utilise the NetLogo's network extension[4], thus this extension is also included in UWAB.

If the scale free network structure is selected, household agents are created, added one by one, forming one link (friendship) to a previously added household agent, until a preset number of total household agents population is reached. The more links (friendships) a household agent already has, the greater the probability that new household agents form links (friendships) with it when they are added.

[4] https://github.com/NetLogo/Network-Extension

If the small-world network structure is selected, household agents are created in a (total household agents population / 10) x 10 grid where each household agent is connected to all of its neighbours. This connected lattice is then turned into a small-world network structure by adding some long range links (friendships) with a probability of connecting inversely proportional to the distance between two household agents raised to the clustering-exponent. A clustering-exponent of 2.0 is typically used (Wilenski, 2006).

The value of the total household agent population must be low enough to satisfy model efficiency and high enough to be able to represent the heterogeneity of a domestic water use population. Due to computing limitations it is necessary to scale down the population for the simulation. Such scaling down is not uncommon in water use related agent based models. For example, Galan et al. (2009) created 12500 agents for simulating 125000 families (scaling down ration = 0.1), Becu et al. (2003) created 325 agents for simulating 2500 farmers (scaling down ration = 0.13), Athanasiadis et al. (2005), used 100 cellular automata for simulating more than a million of domestic water users (scaling down ration = 0.0001) and finally, Barthel et al. (2008) created 50000 agents for simulating a total of 10.8 millions of inhabitants of the upper Danube catchment (scaling down ration = 0.005).

b. Setup household agents command

During the setup, household agents command values are assigned to the household agents' variables. These values are either set using the NetLogo code, meaning that the modeller has information regarding their distribution in the modelled population or they are sampled by the distribution created using global variables (experimental or not).

5.2.2. Model's run procedure

The run procedure uses commands to simulate the agents' behaviour. There are three types of commands under the run procedure: the water demand management commands, which create the policies that affect the agents' behaviour and "inform" the agents regarding the cost of their domestic water use; the population behaviour commands that household agents follow; and the write and export of results commands, that gather the results for each time step and export them at the end of the simulation.

The following paragraphs describe the water demand management and the population behaviour procedures that consist of the main commands that the household agents use in order to decide regarding their water demand behaviour state.

a. Water demand management command

The purpose of this model is to capture the effects of policies and environmental pressures to water demand behaviour of urban households focusing on water conservation attitudes. The household agents are affected by water policies such water saving awareness campaigns, water price changes and water restrictions. It is possible using the UWAB to either set (reverse-engineer) different water policies to reproduce a historical water demand management strategy (as in Chapter 7) or to create different strategy scenarios (experiments) with one or more water demand management policies running during the same time or at different time intervals and for different durations (as in Chapter 8).

To set up the model it is necessary to have a clear roadmap regarding the implementation period of water demand management strategies in respect to the simulation time frame. This roadmap may be historical or scenario based. For example, Figure 5-4 gives several examples where different responses to a drought event (months 5-8) are being explored within a 12 month simulation.

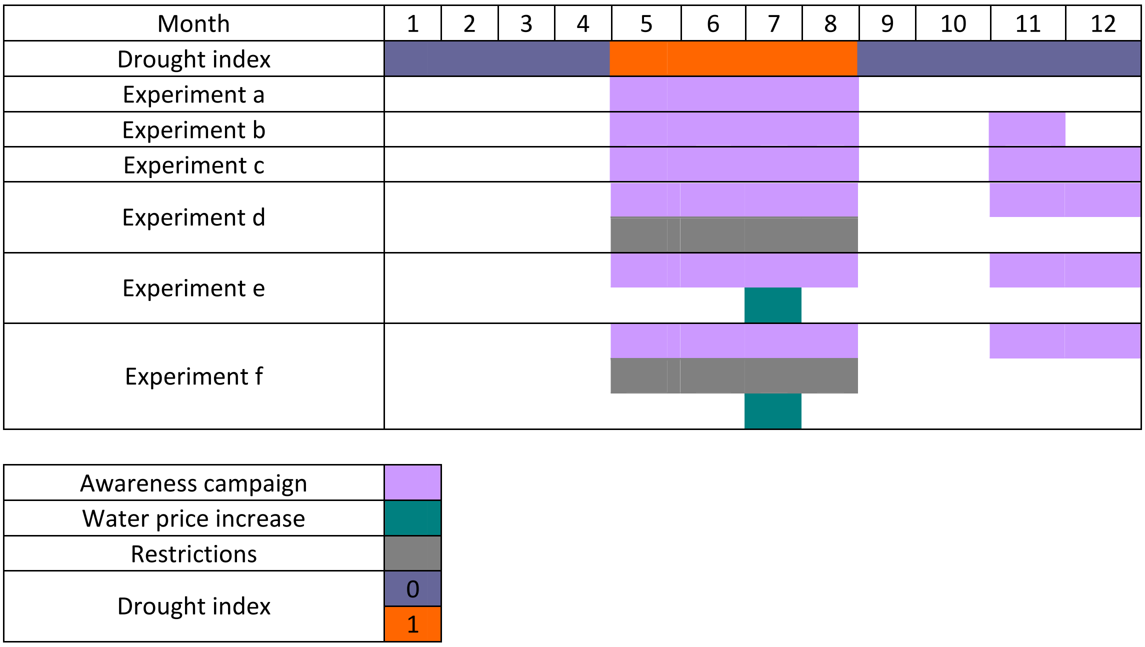


Figure 5-4 Example of different experiments for water demand management strategies

The effects of water saving awareness campaigns and water price changes are taken into account during the calculation of the social impact exerted to the household agents. Both effects are considered as “information transmitted to the public” by the model. These two pressures are included in the external influence (h) parameter of the social impact equation 4-1 presented in Chapter 4. The effect of water restrictions is included in the behavioural intention function that estimates the “energy” of every water demand microstate in the water demand behaviour procedure, see paragraph 4.2.5, session b. Water demand behaviour procedure.

The following paragraphs present the main variables that are required to be set for the implementation of water demand management procedures.

- **Water saving awareness campaign**

The variables that shape water saving awareness campaigns are:

- the influence strength of the water saving awareness campaigns. This is an experimental variable and its value is defined through calibration (as discussed in Chapter 4 paragraph 4.2.3. State variables and scales, session b. Experimental variables)

- the onset and end of the awareness campaign which can be inserted and changed in the code tab of the model.

During this procedure the modeller chooses the number and the time frame of the water saving awareness campaigns based on the water demand management roadmap. The influence strength is set through UWAB's interface and is used by the household agents to sample the value of their intrinsic influence.

- **Water price changes**

The model tries to capture the effect of the information that the price of water has changed and not the effect of the actual price change on demand, because it focuses on the change of attitude from a social impact perspective. As such, an increase or decrease of the water price will affect the population by adding an external influence parameter.

The variables that shape water price changes are:

- the influence strength of the water pricing changes which is an experimental variable, defined through calibration as presented in Chapter 4 paragraph 4.2.3. State variables and scales, session b. Experimental variables)
- the increase or decrease of water prices and
- the beginning and end of the transmission of this information

During this procedure the type and time frame of the transmission of water price changes information is selected based on the water demand management roadmap. The influence strength is set through UWAB's interface and is used by the household agents to sample the value of their intrinsic influence (see paragraph 4.2.3. State variables and scales, session b. Experimental variables, subsection b.2.v. and b.2.vi.).

- **Water restrictions**

The time frame of water restrictions may be set using the NetLogo code. A variable is inserted in the "energy" function of the different microstates that favours the water conservation behaviours.

b. Household agents' behaviour command

The household agent's behaviour command includes four processes:

- **Population change process**

The model focuses on the urban population that resides or moves into a specific area. In order to simulate the change of the population of the area under investigation, agents create other agents which inherit their ancestors' characteristics thus keeping the distribution of the population's features the same. Offsprings create a connection with one agent (randomly selected) that is linked with an above average number of other agents, following the "rich gets richer" principle of the free-scale network structure.

- **Social Impact process**

During the social impact process the household agents estimate the impact from the water demand management procedures and their social network and decide whether or not to change their opinion based on the Social Impact Theory explained in Chapter 2 and the specific adaptation and rules created for the purposes of this work presented in Chapter 4.

- **Water demand behaviour process**

During the water demand behaviour process the household agents estimate the behavioural intention for each water demand state and select one to implement during the following three months opinion based on the Theory of Planned Behaviour explained in Chapter 2 and the specific adaptation and rules in this work presented in Chapter 4.

- **Water demand behaviour review process**

During the water demand behaviour review process the household agents estimate the value of a factor "favouring" one of the water demand states that is fed back into the water demand behaviour process based on the specific rules created in this work and presented in Chapter 4.

c. Write and export of results command

The final procedure of the model is the collection of the results and their export into a CSV format. At the end of every time step the number of the agents that have selected each one of the three water demand behaviour microstates is written in a list. The results are gathered in different lists depending on the characteristics of the agents. These results are exported in a CSV format at the end of the simulation.

5.3. UWOT model

As explained in Chapter 4, UWOT requires a setup procedure outside the modelling interface in order to use it in the proposed modelling platform. This setup procedure provides UWOT with the necessary initial conditions for running the simulation of the evolution of domestic water demand. A typical example of UWOT simulation results can be seen in Figure 5-5.

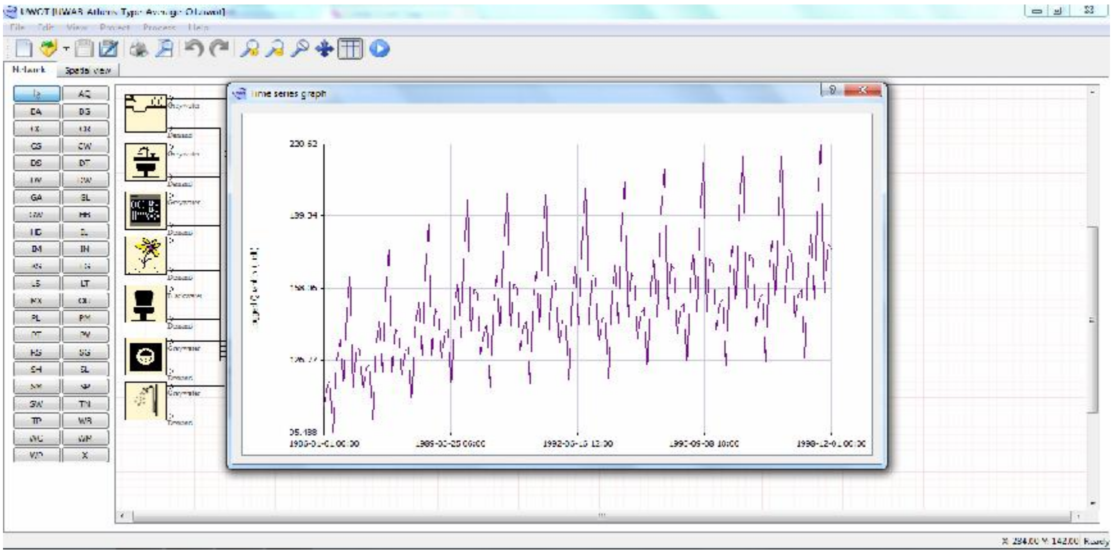


Figure 5-5 Results of UWOT simulation

5.4. Linking UWAB with UWOT

Figure 5-6 presents the sequence of the procedures in order to link UWAB with UWOT. UWAB needs information regarding the water bills that the households receive. UWOT is used to create these water billing information (Figure 5-6 process 4. Calculate water bills per household water demand state). This information is imported into UWAB to proceed with the water demand review process. After running UWAB there are two types of results available: the results of UWOT, in the form of water demand time series per household water demand type and conservation level and the results of UWAB in the form of number of households agent time series per household agent's water demand state (*low* water user with no, low or high conservation level, *average* water user with no, low or high conservation level and *high* water user with no, low or high conservation level). These results are then integrated, by multiplying each water demand time series by the number of households adopting it in order to produce the total monthly water demand (in l/p/d) for the entire population of the area under investigation.

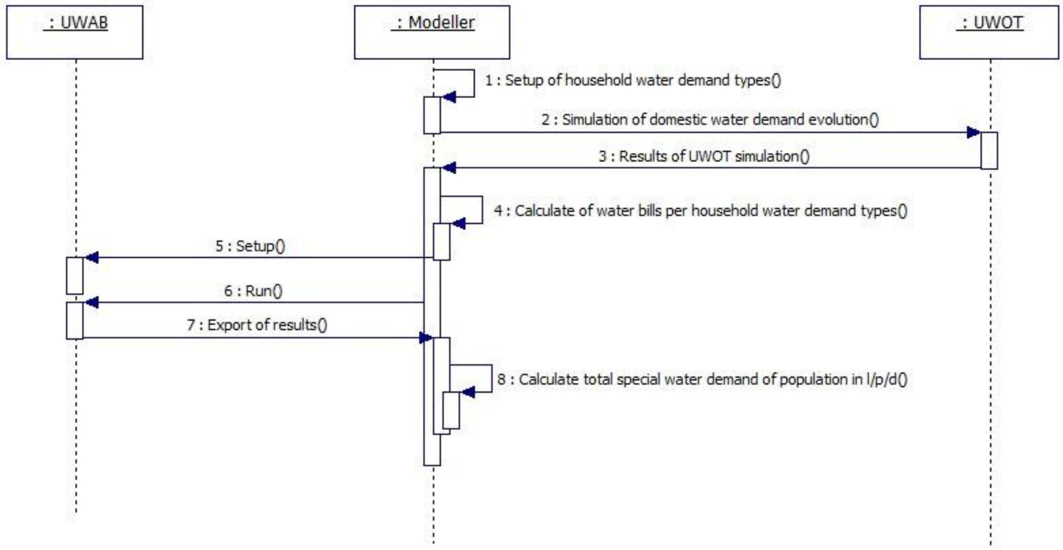


Figure 5-6 UML diagram presenting the linking of UWAB with UWOT

5.4.1. Validation of the UWAB – UWOT modelling platform

UWAB's sensitivity analysis and optimisation process is implemented using Matlab's Global Optimisation toolbox and the multi-objective genetic algorithm. Figure 5-7 presents the optimisation procedure which is applied using the objective function presented in Chapter 4. A java code is created in order for Matlab's optimisation process to communicate with the UWAB (Figure 5-7). At each iteration, the multi-objective genetic algorithm uses the individuals with the best fitness, in the current generation, to create the next generation either by mutation (making random changes to a single parent) or by crossover (combining the parents' characteristics). These parameters are communicated to NetLogo, through the java code. NetLogo simulates the households' behaviour and exports the number of households that select each water demand state per month. NetLogo runs with the same parameters and different randomisation parameters for ten times and Matlab uses the average of the results of these ten runs. These results are then translated to a mean monthly water demand by multiplying the number of households in each water demand type with the mean water demand of each water demand type.

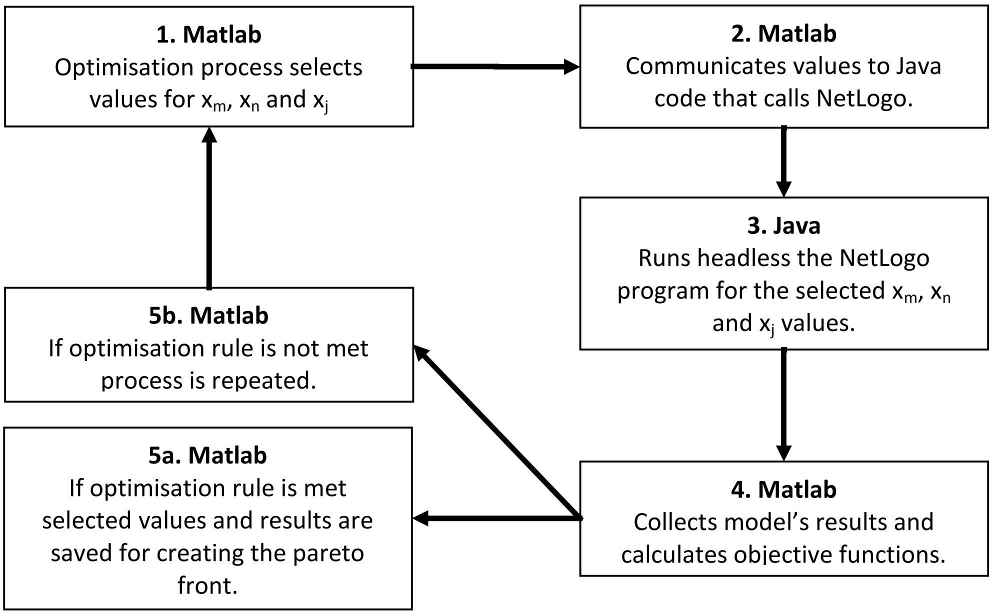


Figure 5-7 Diagram for optimisation procedure

5.5. Summary

This Chapter presented the models developed to implement the methodology proposed in Chapter 4. An agent based model, UWAB, is developed using the NetLogo agent based modelling platform. This Chapter describes the commands and procedures of UWAB. Furthermore, in this Chapter, the UWOT's setup and run interface is presented for simulating the evolution of domestic water demand. Finally, the link between these two models is implemented using Matlab and Java Virtual Machine.

Chapter 6 presents the case study of the urban water system of Athens on which the modelling platform and method will be tested.

Chapter 6. Case study: the Athens urban water system

6.1. Introduction

Athens was selected as a case study for demonstrating and testing the proposed method and models for two reasons: Firstly, the availability of information regarding the state of the urban water system due to the close cooperation of the National Technical University of Athens with the Athens Water Supply and Sewage Company (EYDAP S.A.) and secondly, due to the challenge of applying the proposed methodology in cases with little available data regarding the beliefs and attitudes of society regarding water resources management in an effort to develop a methodology robust enough for transfer elsewhere. The required types of data and their potential sources are summarised in Table 6-1.

Table 6-1 Type of information per sub-system and sources

Modelling platform's sub-system	Data sets	Type	Source
UWOT	Athens urban water system design, streamflows, reservoir levels, system's operation rules	Qualitative / Quantitative	Water utility, NTUA, scientific literature
	Water demand evolution, in-house appliances, frequencies of use	Qualitative / Quantitative	Water utility, scientific literature
UWAB	Socio-demographic characteristics, water demand management measures, water demand behaviour, water conservation attitudes, influence factors	Qualitative	National Statistical Office, tailor-made surveys, scientific literature

The following paragraphs present the information needed for implementing the modelling platform in Athens.

6.2. The Athens urban water system

6.2.1. The Athens water supply system

Athens is the capital and the largest city of Greece. Athens' climate is characterised by mild wet winters and dry summers, with an overall low annual rainfall (long term annual average of the past 100 years = 400 mm) (Mamasis and Koutsoyiannis, 2007). Water supply in the city of Athens has always been a major development issue. Even before 400 BC, the hot and dry climate and the small rivers flowing around Athens were not enough to satisfy the water demand of its 200.000 inhabitants.

In 594 BC the first water demand management measures were implemented by Solon that ensured that all citizens had access to water and designated officials were responsible for ensuring the equitable distribution of water to the citizens (Xenos et al. 2002). Around 400 BC, Athens water supply included private and public wells, fountains and springs, aqueducts that carried water from the mountains around Athens and tanks to collect rainwater. Around the 2nd century AD, while Hadrian was the Roman Emperor, a 25 km long aqueduct was built that brought water from the Mount Parnitha to the city of Athens. The Hadrian aqueduct over the centuries was destroyed and rebuilt and it was in use until 1931, when the dam and aqueduct of Marathon was built. At that time the city's consumption was about 12 million cubic meters with a population of approximately 800.000 inhabitants.

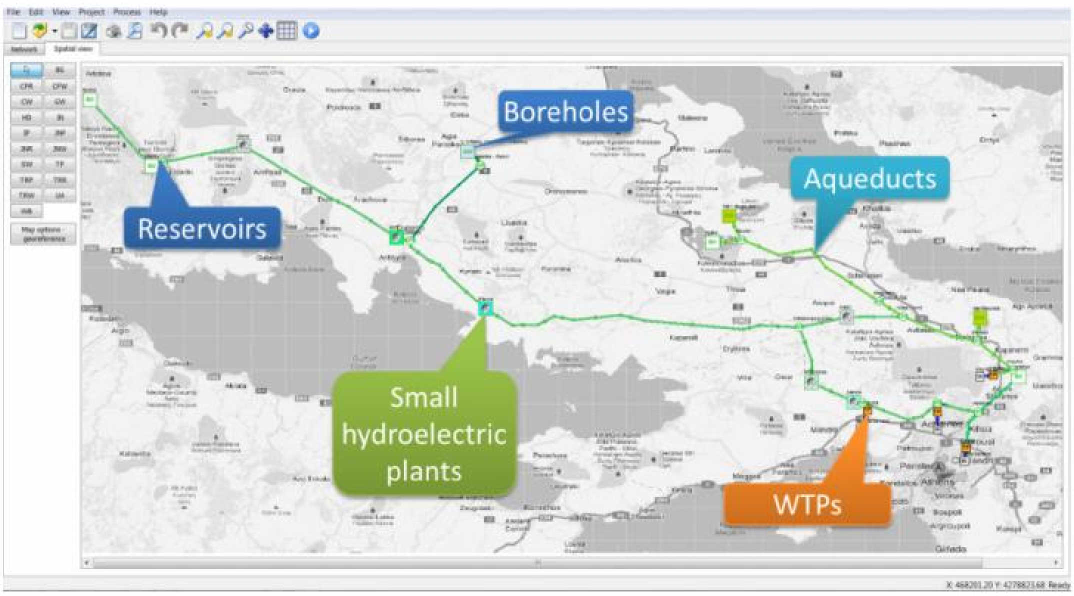


Figure 6-1 Athens water supply system (Baki and Makropoulos, 2014)

Figure 6-1 presents the Athens water supply system as it has evolved in the past 80 years. In 1958, the aqueduct of Hylike, that carried water from the homonymous natural lake, was created to meet the increased consumption of 49 million cubic meters. In 1979, to meet the increased demand of around 280 million cubic meters, the Mornos reservoir and aqueduct was built, bringing water from the Mornos river, situated at about 200 km west of Athens. In 1989, the largest water consumption was recorded at around 380 million cubic meters. The increased consumption and a persistent drought event (1988-1994) led to the decision to divert Evinos river to strengthen the Mornos reservoir (diversion 1996, reservoir operation 2001) (Mamasis and Koutsoyiannis, 2007). Nowadays Athens's water supply system has evolved, reaching the current complex shape, that consists of 350 km of main aqueducts, 4 dams, 100 groundwater boreholes spread in 4 groundwater bodies, 15 pumping stations and 4 treatment plants all covering a total area of 4000 km2 and serving a total population of around 4 million people (Mamasis and Koutsoyiannis, 2007).

The system is run by the EYDAP S.A. which was established in 1980 merging the Anonymous Greek Cities Water Company of Athens - Piraeus (EEY) and the Sewerage Capital Organization (OAP). EEY was established in 1974 taking over from ULEN SA. ULEN was a US water company that in 1924 established the first water company of Athens in corporation with the Bank of Athens and the Greek state. Nowadays, EYDAP S.A. is a publicly traded company. In 1999, the main assets of the Company, namely dams, reservoirs, aqueducts and external pumping stations were absorbed by the Company Assets Public Entity, remaining the property of the Greek state. In 2012, the share of the Greek state amounting to 61.33% passed to the Hellenic Republic Asset Development Fund (ΤΑΙΠΕΔ) (source: EYDAP website https://www.eydap.gr/).

The overall storage capacity of the hydrosystem approaches 1400 hm^3, but just two of the reservoirs, the Mornos reservoir and the natural lake Hylike, hold 88.5% of it. Although Evinos reservoir (in operation since the summer of 2001) has comparatively small capacity, it receives the largest inflows among all four reservoirs. Water from Evinos is diverted through a tunnel and stored in the neighbouring Mornos reservoir (Efstratiadis et al., 2004). EYDAP SA operates its hydrosystem using the Hydronomeas software that is able to assist the management of hydrosystems with multiple contradictory water uses and operating goals, calculating complex multi-reservoir systems as a whole (Koutsoyiannis et al., 2001).

In this research, the Athens water system was modelled through UWOT. The model used was first presented by Rozos and Makropoulos (2013) and included simplifications, such as the simulation of only two out of the four treatment plants, to reduce the complexity of the supply network without compromising model accuracy. However, they report that these assumptions did not reduce the quality of the results, that are found to be comparable to those of the current model used by the Water Company of Athens (EYDAP S.A) to develop its hydrosystem's operational rules (Hydronomeas).

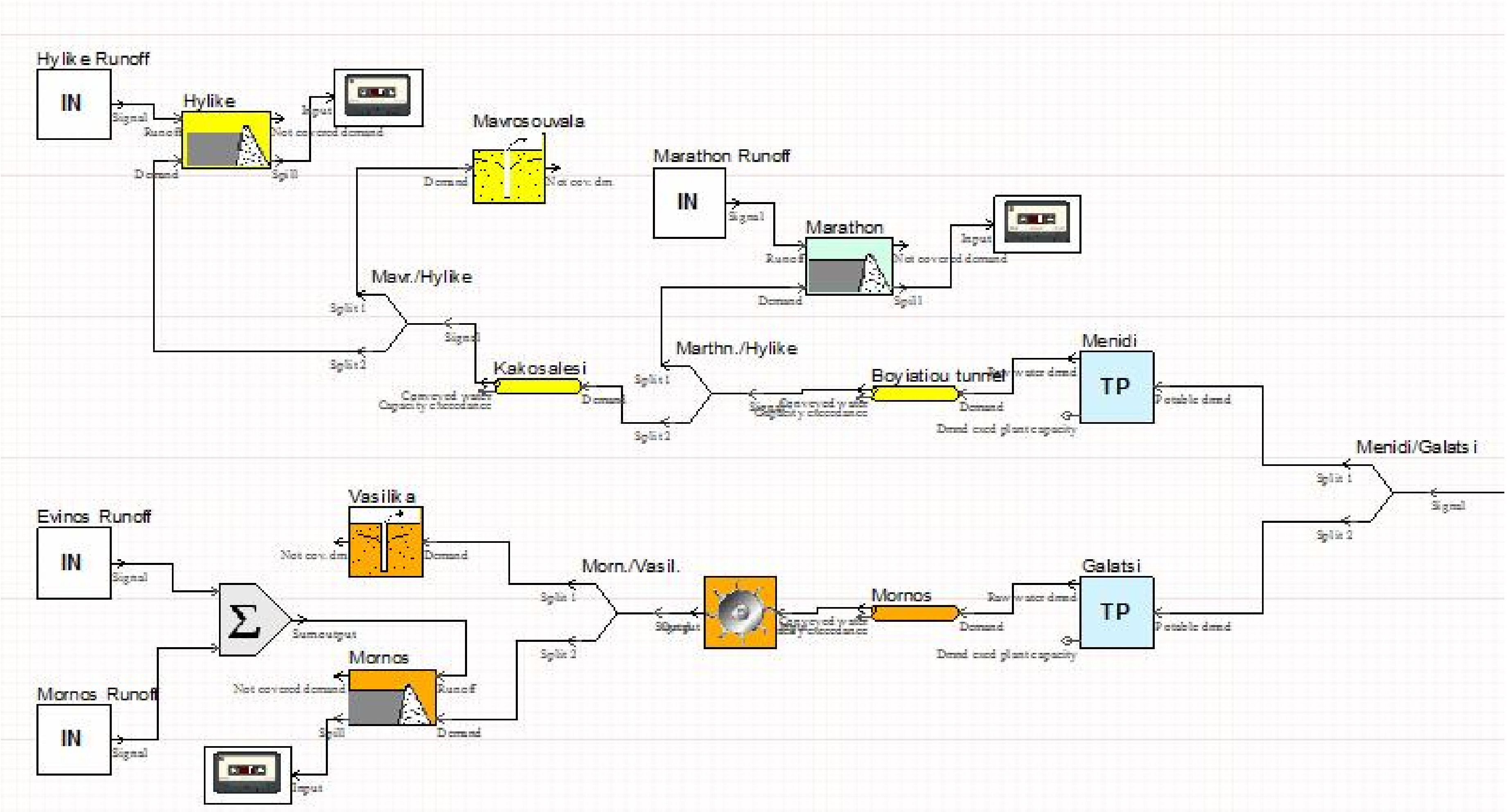


Figure 6-2 Representation of Athens external water supply system in UWOT (Rozos and Makropoulos, 2013)

This UWOT model has been further developed by Baki and Makropoulos (2014), incorporating all of the water treatment plants and small hydroelectric projects, trying to represent the Athens water system as realistically as possible. This advanced representation of the Athens water system was calibrated to achieve a 99% reliability. The calibrated model is used in this research for modelling future scenarios (Chapter 8). The required historical data for the Athens water supply network can be found in www.itia.ntua.gr/eydap/db.

6.2.2. The Athens water demand evolution

EYDAP S.A. has approximately 3.2 million direct customers (1.85 million connections), with a total water supply network length of 9500 km and a sewerage network length of 8000 km. In 2011, EYDAP S.A. was responsible for supplying 185 million cubic meters of water to 42 Athens' municipalities. The mean monthly water demand per capita was at around 160 litres per person and per day with the highest demand of around 280 litres per person per day in the suburbs of Vari, Voula, Vouliagmeni and the lowest demand of around 113 litres per person per day in the suburbs of Nikaia, Ag. I. Rentis and Elefsina (Figure 6-3).

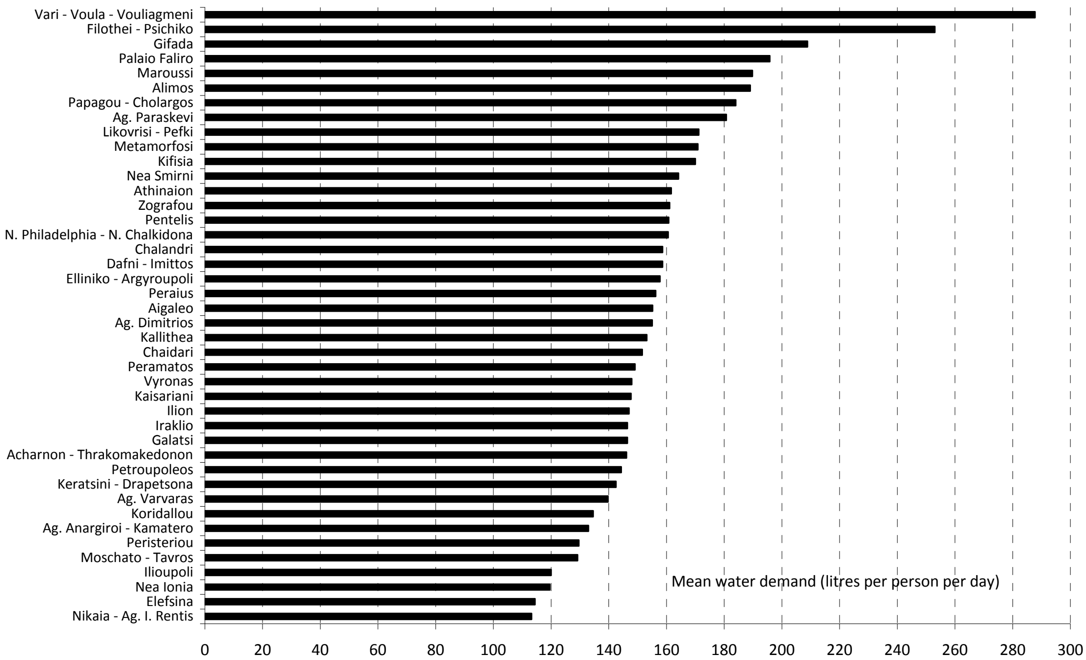


Figure 6-3 Mean domestic demand in EYDAP's responsibility area for 2011 (EYDAP, 2014)

It is worth noting that the industrial water consumption started to decline by the end of the 1980s mainly because many industries left EYDAP's area of responsibility. In addition, from 1993 onwards the municipal water consumption increased because of the addition of many municipalities to EYDAP's indirect area of responsibility (EYDAP, 2009).

In terms of the Athens' water demand seasonality, based on EYDAP's water resources management report of 2009, it depends mainly on weather conditions and the movement of people due to holiday seasons. In particular, domestic water demand decreases during the summer months due to the holiday season when a high percentage of Athens population moves towards the seaside. In addition, the highest consumptions are evident during the month of July, which combines high concentration of population and meteorological conditions that favour a higher demand of domestic water (EYDAP, 2009).

The evolution of domestic water demand during the 1980s presented an annual increasing rate of about 6%, mainly due to the increase of the quality of life of Athenians during the 1980s (Germanopoulos, 1990). This increase rate is evident throughout the 1980s (to better observe this, 1982 must be excluded from the calculation of the annual rate, since in 1982, a major increase of water price was applied and the total water demand was considerably affected (Germanopoulos, 1990). Germanopoulos published his water demand projections in Athens in 1990 and thus did not include the effects of the drought period (Germanopoulos, 1990). He forecasted that during the 1990s the annual increase rate would be much lower, around 1.30%, mainly due to the projected stabilisation of the quality of life conditions.

Table 6-2 presents the projected monthly water demand without the effects of drought management policies and the annual trend taking 1986 as a baseline year. Figure 6-4 shows the comparison between the projected mean monthly water demand based on the annual trends (Table 6-2) and the actual mean monthly water demand as reported by EYDAP (EYDAP, 2009). EYDAP's data present a higher overall increase of mean water demand in Athens, compared to that projected by Germanopoulos study, attributed to a corresponding increase of the quality of life. Additionally, another interesting feature of Figure 6-4 is that the effects of the water demand management measures during the Athens' 1988-1994 drought period are clearly evident.

Table 6-2 Projected mean monthly water demand based on annual trend

Year	Annual Change in Domestic Water Demand (from Germanopoulos p. 81)		Mean monthly water demand (l/p/d) without effects of drought management policies	Trend (1986 as a baseline year)
1986	1980s	6%	125	0%
1987	1990s	1.30%	133	6%
1988			140	12%
1989			149	19%
1990			151	21%
1991			153	22%
1992			155	24%
1993			157	25%
1994			159	27%
1995			161	29%
1996			163	30%
1997			165	32%
1998			167	34%

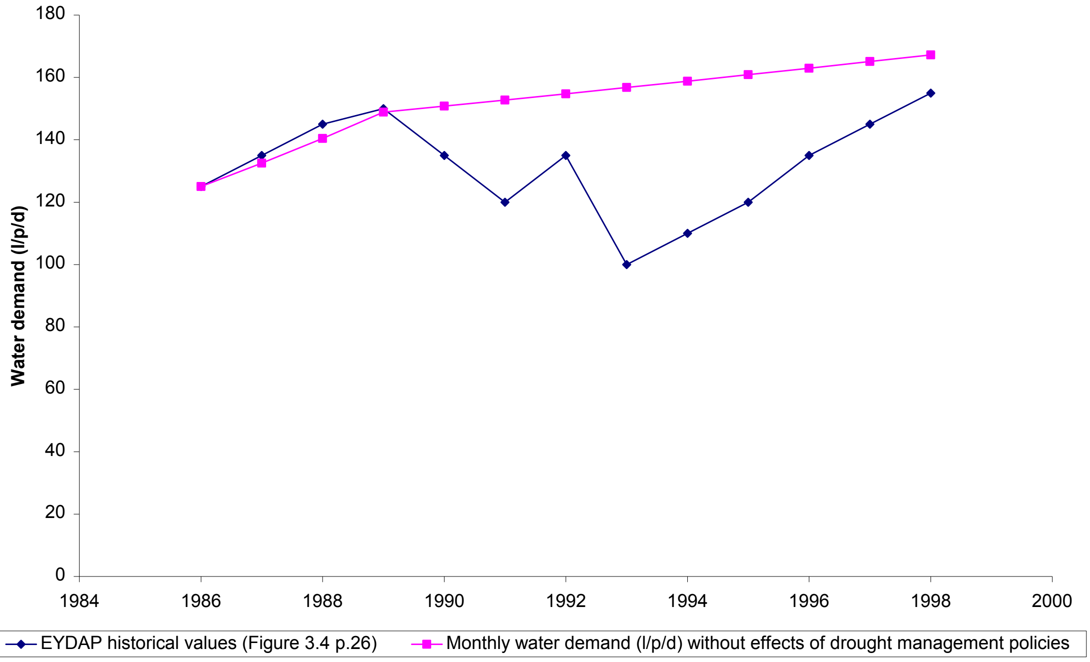


Figure 6-4 Comparing projected and actual mean monthly water demand for Athens during 1986-1998

6.2.3. The 1988-1994 drought of Athens

Figure 6-5 presents the evolution of consumption in comparison to the evolution of Athens' population, the evolution of the water supply system and the implementation of water demand management measures.

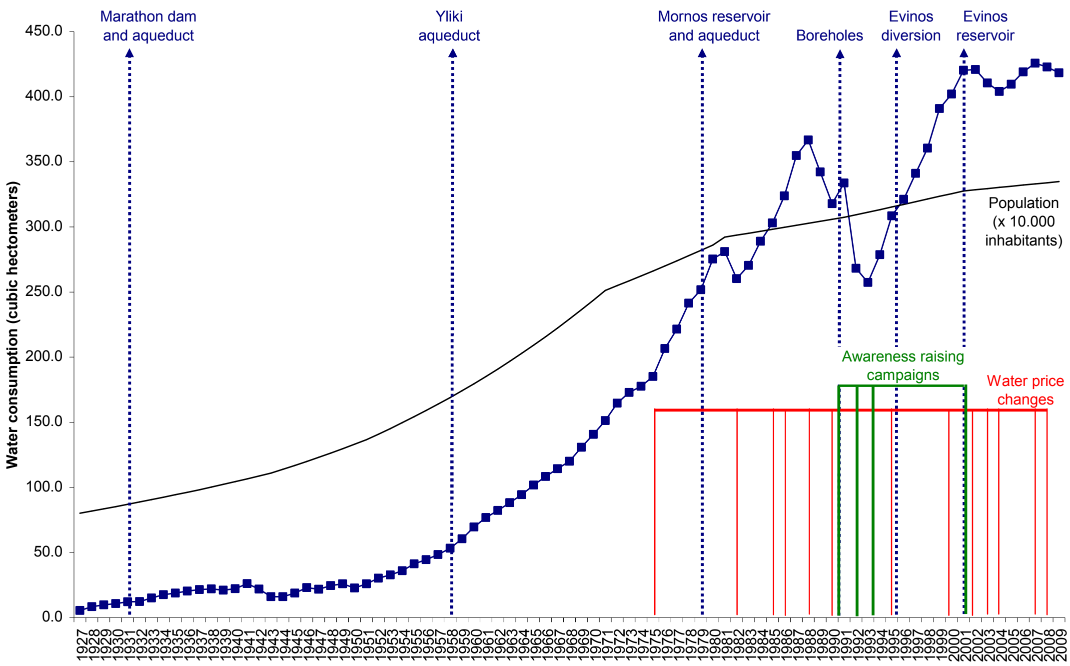


Figure 6-5 Evolution of consumption, population, water works and water demand management measures (water price changes & awareness raising campaigns) (information taken from EYDAP, 2009, Efstratiadis, 2012, EYDAP pricing policy, 2013, EYDAP communication, 2014)

In 1989 the highest, until then, consumption in Athens was recorded (376 million cubic meters). This large consumption coincided with a significant reduction of inflows into the reservoirs, which marked the beginning of a drought period that persisted for about seven years (Mamassis and Koutsoyiannis, 2007). The drought brought the system to each limits and required water demand management measures to reduce water demand.

During the drought period of 1988 – 1994 Athens' water reserves reached the lowest record ever and remained for a long time so low (less than 50% of the long term average) that by the end of 1994 water reserves were barely enough to satisfy the demand for less than a year (Mamassis and Koutsoyiannis, 2007). The main response to this drought pressure in terms of water demand management was the substantial increase of water prices, an average of 240% across all levels of consumption, extensive water saving awareness campaigns in 1990, 1992 and 1993 and outdoor water restrictions in 1993 (EYDAP, 2009, Kanakoudis, 2008).

The effect of these policy measures was an approximate 33% drop of domestic water demand, from an average volume of 150 litres per inhabitant per day in 1989 to 100 litres per inhabitant per day in 1993 (Mamassis and Koutsoyiannis, 2007). Following the end of the drought period and the extension of the water supply network, water saving awareness raising campaigns were stopped and water consumption returned to 150 litres per inhabitant per day by 1997 and continued to increase mainly due to the increase of living standards (EYDAP, 2009).

It is evident, in retrospect, that awareness campaigns and the diffusion of information related to the risk of running out of water and the increase of water prices, had a major impact in the water saving attitudes of the population of Athens. When the drought was over and even though the prices remained at a higher level than before the drought the consumption levels increased (Mamassis and Koutsoyiannis, 2007, Kanakoudis, 2008). This is interesting because it supports the assumption that it was not the price per se that changed the behaviour but the perception of the price change.

6.2.4. Water demand management measures in Athens

The main water demand management measures implemented by EYDAP in Athens are water price changes and awareness raising campaigns. In periods of high water shortages, such as the persistent drought of 1988-1994 restrictions of outdoor water use were also used (Kanakoudis, 2008).

Table 6-3 present a summary of the awareness raising campaigns that targeted the drought (communication with EYDAP's Public Relations in June 2014)that was sent .

Table 6-3 Awareness raising campaigns for water use during Athens drought period

Year	Type of campaign	Main message	SLOGAN (in Greek)
1990	Informative / Warning	There is not enough water	Προσέχουμε για να έχουμε
1992	Informative	Reduce wasting water	Πρόσεχε το νερό
1993	Informative (proactive)	Use water wisely	Νερό για ζωή, όχι σπατάλη

From 1986 until today water prices have changed either due to water demand management strategies or due to national economy changes such as the transition from the drachma to the euro. Table 6-4 presents the evolution of EYDAP's water tariffs from 1986 to 2013.

Table 6-4 EYDAP water tariffs (1986-1998)

	1986	1988		01/90	
Mean fixed cost for supply pipes 5/8" – 3/4" (domestic supply in drachmas)	125	156.5		185	
Cubic Meters	d/m^3	m^3	d/m^3	m^3	d/m^3
0-4	20	0-6	29	0-20	29
4-15	30	6-20	35	20-27	67
>15	45	>20	55	>27	80

	05/90	07/91	01/92	07/92	12/96
Mean fixed cost for supply pipes 5/8" – 3/4" (domestic supply in drachmas)	185	198	198	198	198
Cubic Meters	d/m^3	d/m^3	d/m^3	d/m^3	d/m^3
0-5	60	48	51	102	117
5-20	90	72	77	154	178
20-27	200	200	214	428	514
27-35	280	280	300	600	724
>35	350	350	375	750	900

	07/00	04/02	04/03
Mean fixed cost for supply pipes 5/8" – 3/4" (domestic supply)	207.5 (drachmas)	217.165 (drachmas)	< 30 m^3 0.52€/m^3 30 – 60 m^3 0.80 €/m^3 > 60 m^3 1.5 €/m^3
Cubic Meters	d/m^3	d/m^3	€/m^3
0-5	122	127.98	0.38
5-20	188	195.11	0.59
20-27	538	564.36	1.70
27-35	754	790.95	2.38
>35	942	988.15	2.97

	12/04	02/07	10/08
Mean fixed cost for supply pipes 5/8" – 3/4" (domestic supply)	< 30 m^3 0.53€/m^3 30 – 60 m^3 0.82 €/m^3 > 60 m^3 1.54 €/m^3	< 30 m^3 0.55 €/m^3 30 – 60 m^3 0.84 €/m^3 > 60 m^3 1.59 €/m^3	< 30 m^3 0.56 €/m^3 30 – 60 m^3 0.87 €/m^3 > 60 m^3 1.64 €/m^3
Cubic Meters	€/m^3	€/m^3	€/m^3
0-5	0.39	0.4017	0.4138
5-20	0.61	0.6283	0.6471
20-27	1.75	1.8025	1.8566
27-35	2.45	2.5235	2.5992
>35	3.05	3.1415	3.2357

	12/13
Mean fixed cost for supply pipes 5/8" – 3/4" (domestic supply)	1 €/m^3
Cubic Meters	€/m^3

0-5	0.35
5-20	0.64
20-27	1.83
27-35	2.56
>35	3.2

6.3. Results of the applied social research methods

To tackle the unavailability of data regarding people's attitudes and behaviours towards water conservation two quantitative and one qualitative social research studies were undertaken. The quantitative methods, implemented as questionnaires, allow the gathering of raw data to describe water consumption habits (Wisker 2007). The first quantitative study was designed to gather information regarding water attitudes and behaviours from Athenian households. It was implemented as a phone survey by VPRC AEEE during the months of June and July 2013. The second quantitative study was designed to gather focused information regarding the environmental consciousness level, the attitude towards water resources and specific behaviour regarding the frequency of use of household water appliance. It was implemented as an online survey using the free services of the Survey Expression website (http:// www.surveyexpression.com/). Finally, the qualitative research study aimed at an in depth understanding of the shaping factors of attitudes, perceptions, cognitions, attributions and their link to behaviour and decision making.

The following paragraphs present the design and implementation of the quantitative and qualitative social research studies. The studies were focused on Athenian households and this is the first time that the water demand attitude of Athenians has been extensively explored[5]. All studies were undertaken in 2013, therefore only the statistical analysis of the answers was used as input to the case of the Athens 1988-1994 drought period (see Chapter 7). However, raw data from the studies were included in the scenario experiments (see Chapter 8).

6.3.1. Phone survey's results

The lack of quantitative data regarding people's attitudes and behaviours towards water and water technologies was tackled using a survey. This survey was designed to gather as much information as possible regarding household water appliances, attitudes and behaviours towards water conservation and water saving infrastructure. The questionnaire was implemented as a telephone survey by VPRC S.A., a polling Greek company, during the months of June and July 2013. The questionnaire is presented in Annex III (in Greek) and its main sections are:

1. Environmental attitudes and beliefs
2. Water use, attitudes and beliefs

[5] In 2012, the NGO MEDSOS conducted an online survey in 11 major cities of Greece, without however publishing results for the Athenian households.

3. Water demand attitudes
4. Attitudes towards alternative water resources technologies

The survey focused on Athens' urban households thus the majority of the sampled population was from the Region of Athens. Furthermore, households from the islands of the Aegean Sea were also targeted since they represent areas where water scarcity is evident almost annually and that practices such as rainwater harvesting and even grey water recycling are more common (Gkikas and Tsobanoglous, 2009). Thus, the questioned sample consisted of 800 respondents from households in Athens's Region (Attiki) and 200 from the islands of the Aegean Sea. Figure 6-6 presents the distribution of surveyed households from Attiki.

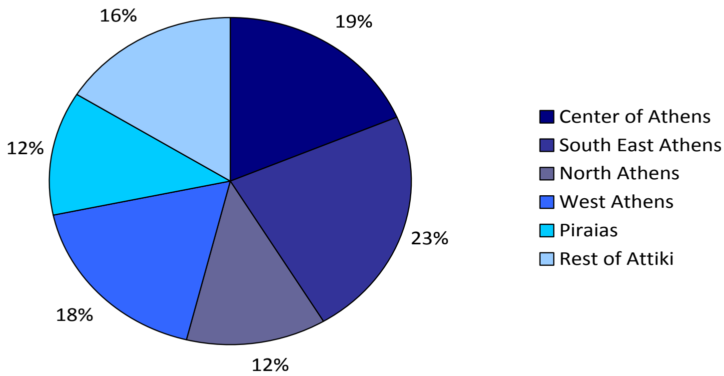


Figure 6-6 Area distribution of questioned households

The socio-economic profile of the sampled population:

- 60% are women;
- 70% is married;
- 55% has children;
- 55% of the households have more than two members;
- 90% owns their house;
- 60% lives in an apartment building;
- 15% has a low educational level, 50% has an average educational level and 35% has a high educational level;
- 40% of the sampled population has a low income, 50% has an average income and 10% has a high income level.
- 60% feels closer to the city and neighbourhood they live in while 30% feels closer to their hometown

The majority (75%) of the respondents appear to trust the media transmissions regarding water resources information. Additionally, around 46% of the sampled population responded that it had actively searched for information regarding water resources during the past 12 months.

The sampled population appears almost divided concerning water conservation only for lowering their water bill. While the majority of the respondents (about 64%, see Figure 6-7) did not know the amount in cubic meters of the water they consume, they knew the amount of euros they pay for water, with a staggering 1.6% not knowing about the size of their water bill (Figure 6-8).

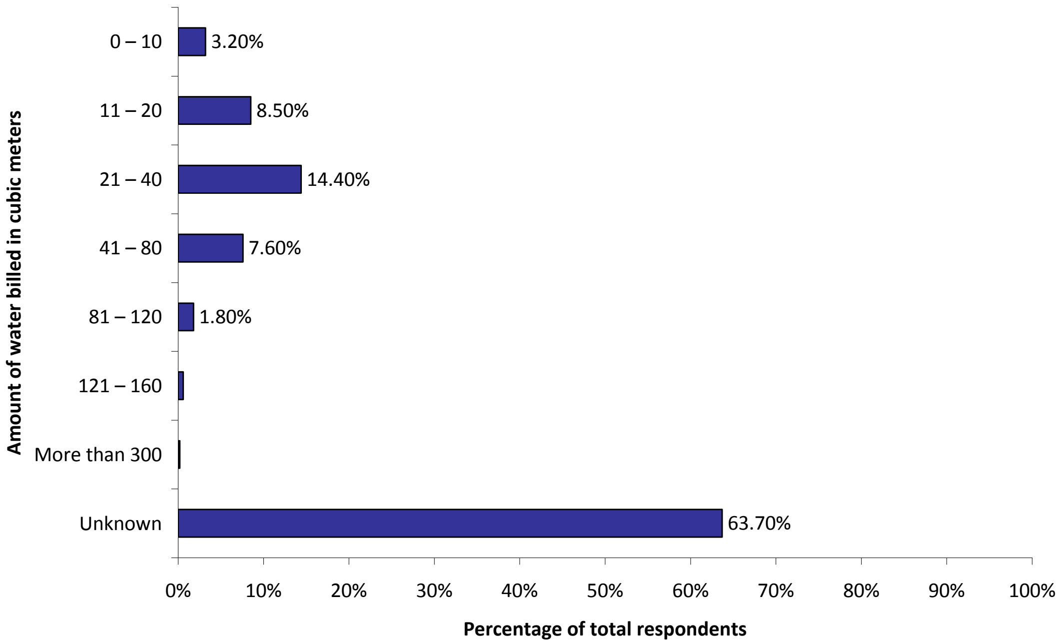


Figure 6-7 Amount of water billed (in cubic meters)

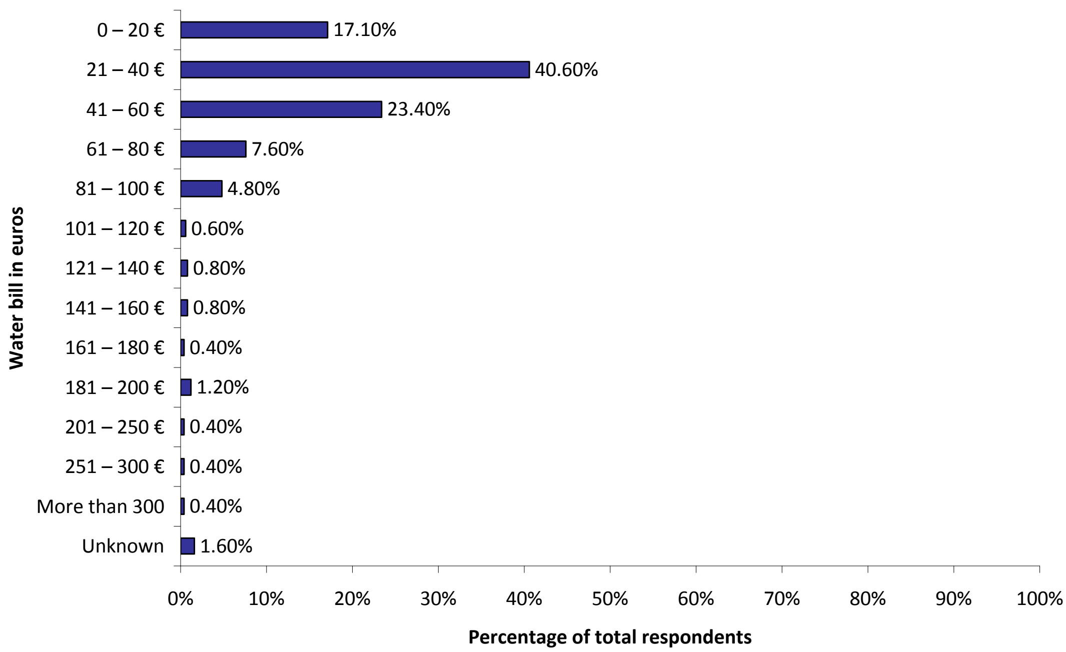


Figure 6-8 Water bill (in euros)

In terms of water demand behaviour, 55% of the sampled population believes that they consume the same or less water than its neighbours, while 14% admits that it consumes more water than its neighbours. In addition, almost 90% of the population reports that they check often if taps are dripping and that they turn off the tap when brushing teeth, soaping and washing the dishes.

The majority of the sampled population owns a shower or uses the bathtub as a shower, owns a washing machine and has a balcony with plants (Figure 6-9). The sampled population appears saturated in terms of water saving in the shower, since almost 90% of the sample prefers shower over bath and 86% showers for less than 10 minutes. Additionally, 99% of the sampled population does not try to decrease the number of showers they take. Nevertheless, more than 50% of the sampled population has one or more showers per day during the winter months and this number goes up to more than 80% during the summer months.

Additionally, it is suggested that other household water uses, such as washing clothes and dishes, watering plants and cleaning the car, have room for water saving, For instance, around 70% of the sampled population uses the washing machine and the dish washer two or more times per week. Moreover, 23% of the sampled population waters their plants (garden or balcony) more than twice per week, mainly with a hose, while only 13% has installed sprinklers. Finally, 25% of the sampled population washes its car, mainly with a hose or a bucket.

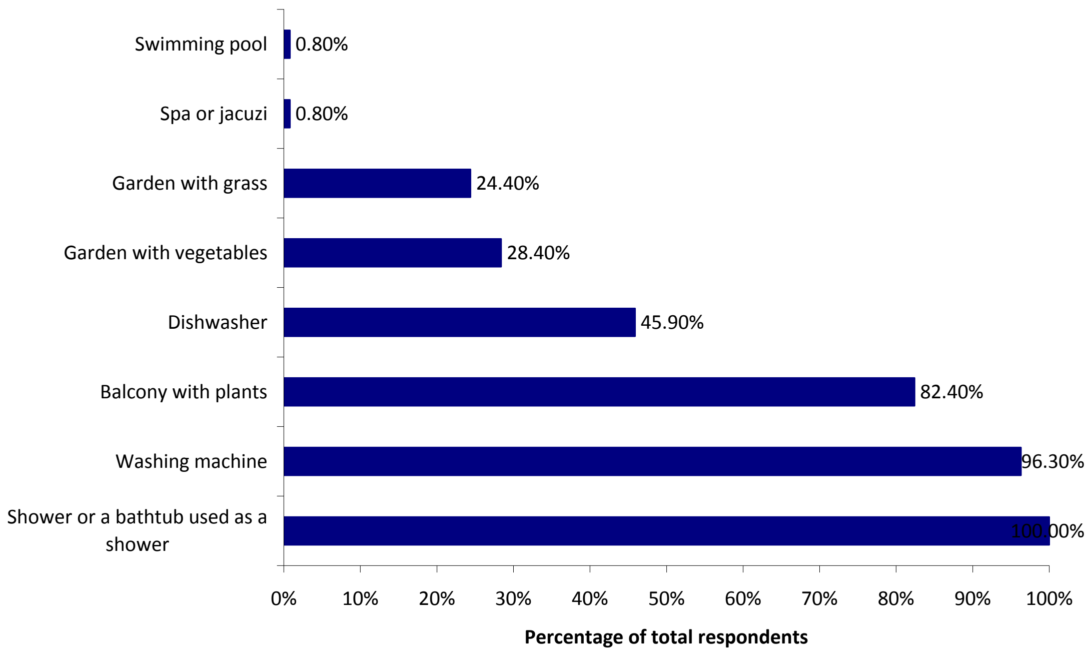


Figure 6-9 Common water appliances within the sampled population

With regard to alternative water resources technologies adoption it may be implied that the market is not saturated with a 1.6% and 1.8% of the sampled population having either a water recycling technology or a rainwater harvesting system in their house respectively. In addition, 1.6% of the respondents replied that they know what the term “grey water” signifies and 2.6% have heard this term in general. Furthermore, the majority of the sampled population (88%) believes that alternative water resources technologies have a significant positive impact to water resources.

Furthermore, 22% of the respondents replied that they are willing to spend money in order to acquire alternative water resources technologies. A total of 26% of the respondents have experienced water restrictions, with an 18% of them living in the islands of the Aegean Sea. Out of the respondents that are positive towards investing in alternative water resources technologies, around 23% has experienced water restrictions at some point in their lives. In addition, a 35% and a 19% of those willing to invest in alternative water resources technologies, live in the islands of the Aegean Sea and in Athens respectively.

Interestingly 20% of those that are interested in using grey water in their household is less than 34 years old. Finally, 8.4% of all the respondents have had previous experience with using alternative water resources, which corresponds to a total of 14% and 7% living in the islands and in Athens respectively.

The respondents were also asked to prioritise effective alternative water resource options as a means to increase water quantity. They opted for:

- public grey water recycling by 14% (21% and 25% living in the islands and in Athens respectively),
- public desalination by 31% (66% and 48% living in the islands and in Athens respectively),
- household grey water recycling by 14% (22% and 28% living in the islands and in Athens respectively) and
- household rainwater harvesting by 34% (59% and 48% living in the islands and in Athens respectively).

With respect to water conservation attitudes (Figure 6-10) the majority of the sampled population believes that their household’s water demand does not cause any impacts to the environment, they are not willing to spend money for acquiring water efficient appliances and they believe that farmers have greater impact to water resources than domestic users. However, 80% of the population believes that they should conserve water even if the rest of the community overuses and more than 50% of the sampled population that they should try to conserve water even without imposed measures.

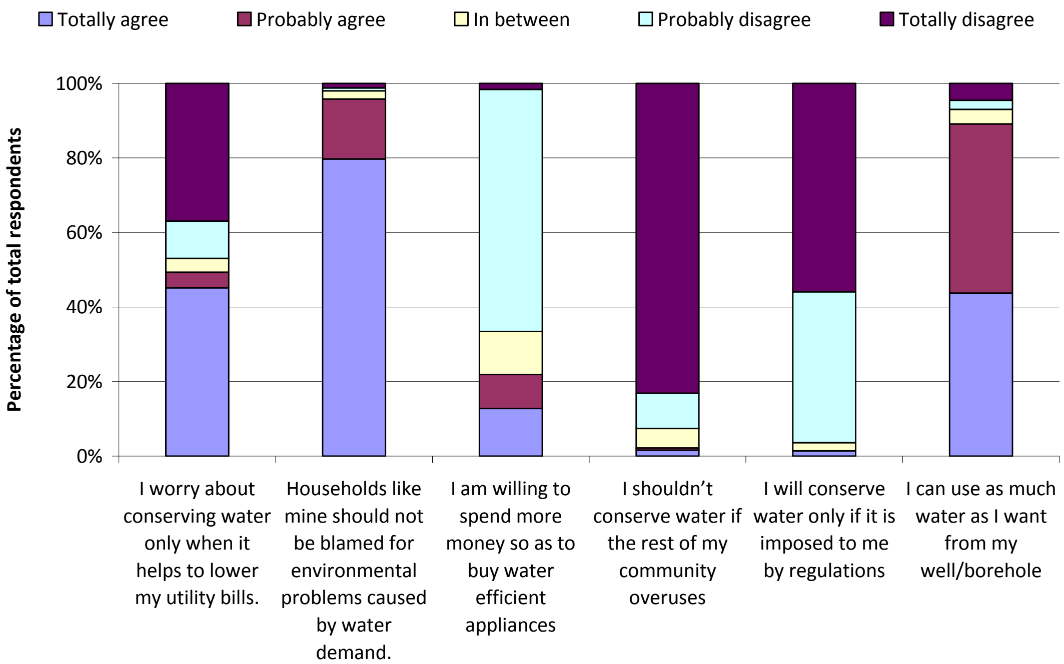


Figure 6-10 Water conservation and consumption attitudes

In terms of general environmentally friendly behaviour, almost 70% of the sampled population often recycles, uses energy efficient devices and bulbs while 50% of the population keeps heating low to conserve energy and 40% uses plants of low water demand (Figure 6-11).

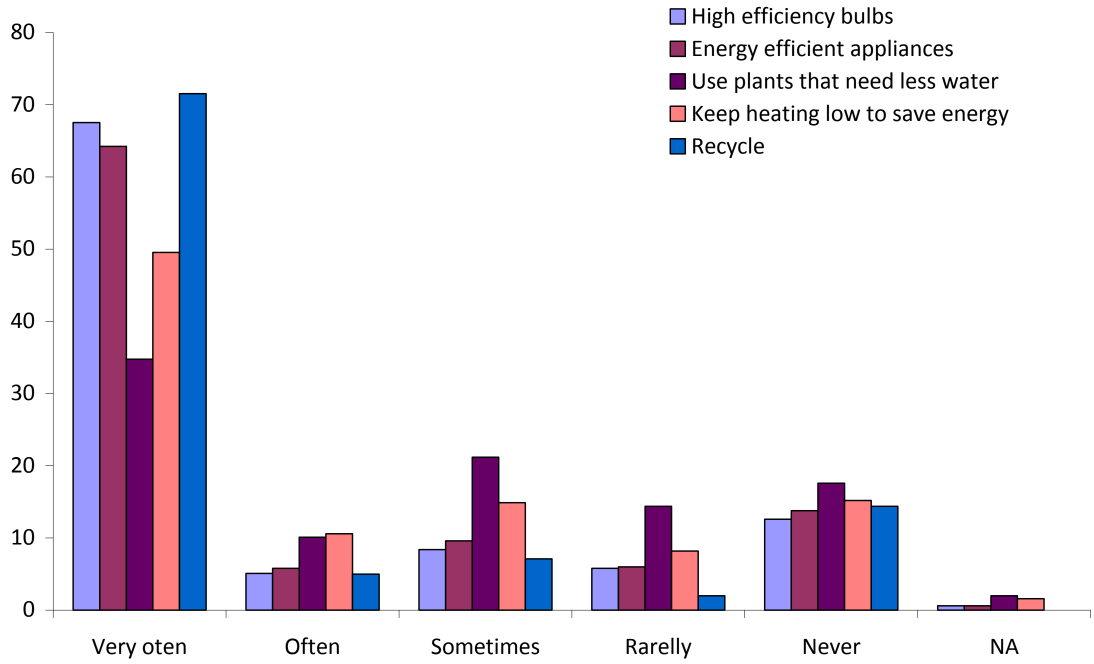


Figure 6-11 Frequency of certain behaviours at home during the past year

Moreover, the environmental consciousness of the respondents was identified by combining their answers into the following six distinct questions:

1. Humans have the right to modify the natural environment to suit their needs
2. The so-called “ecological crisis” facing humankind has been greatly exaggerated
3. Do you often buy high efficiency bulbs?
4. Do you often buy energy efficient appliances?
5. Do you often keep the thermostat low to save energy?
6. Do you often recycle (glass, newspaper, aluminium cans, plastic bottles)?

Those with the higher environmental consciousness were identified as those that are anti-anthropocentrism (Dunlap et al., 2000), (totally disagree with question 1), those that accept the possibility of an ecocrisis (Dunlap et al., 2000) (totally disagree with question 2), those that always make environmentally friendly purchasing decisions (questions 3 and 4) and those that behave in an environmental friendly manner (questions 5 and 6). Additionally, all the respondents that agreed, somewhat agreed and neither agreed nor disagreed, with questions 1 and 2 and those that never or were rarely engaged with environmentally friendly behaviours (questions 3 to 6) were labelled with low environmental consciousness. The remaining respondents were labelled to have an average environmental consciousness.

This analysis led to the conclusion that around 14% of all the respondents could be considered to have high environmental consciousness while 2% could be labelled with low environmental consciousness. It is worth mentioning that 50% of the former category has a higher educational level, something that is also backed up by literature (Gilg and Barr, 2006).

The categorisation into environmental consciousness levels presented above did not follow an established measurement method, like the New Ecological Paradigm (Dunlap et al., 2000) since the questionnaire was already demanding in terms of surveying time, to incorporate all the questions needed for the New Ecological Paradigm scale.

Nevertheless, this categorisation allowed a combinational evaluation of the answers of the respondents with the aim to shed light to ties between general environmental attitudes and water attitudes and behaviours. Figure 6-12 suggests that almost 100% of the respondents identified as people with high environmental consciousness, behave in a water saving manner by turning off the taps and making sure that taps don't drip. In addition, the majority of those with high environmental consciousness has an energy efficient washing machine and pays less than 60 euros in their water bill. Nevertheless, no one from that group aims at decreasing the number of showers they are taking, and less than 10% recognises water scarcity as the major environmental issue, which allows to assume that water related problems are not believed to be major even from those with the highest environmental consciousness. Finally, almost 100% of those with high environmental consciousness believe that alternative water resources technologies are the best way to combat water scarcity which shows a preference to technical solutions rather than a preference to water related behaviours change.

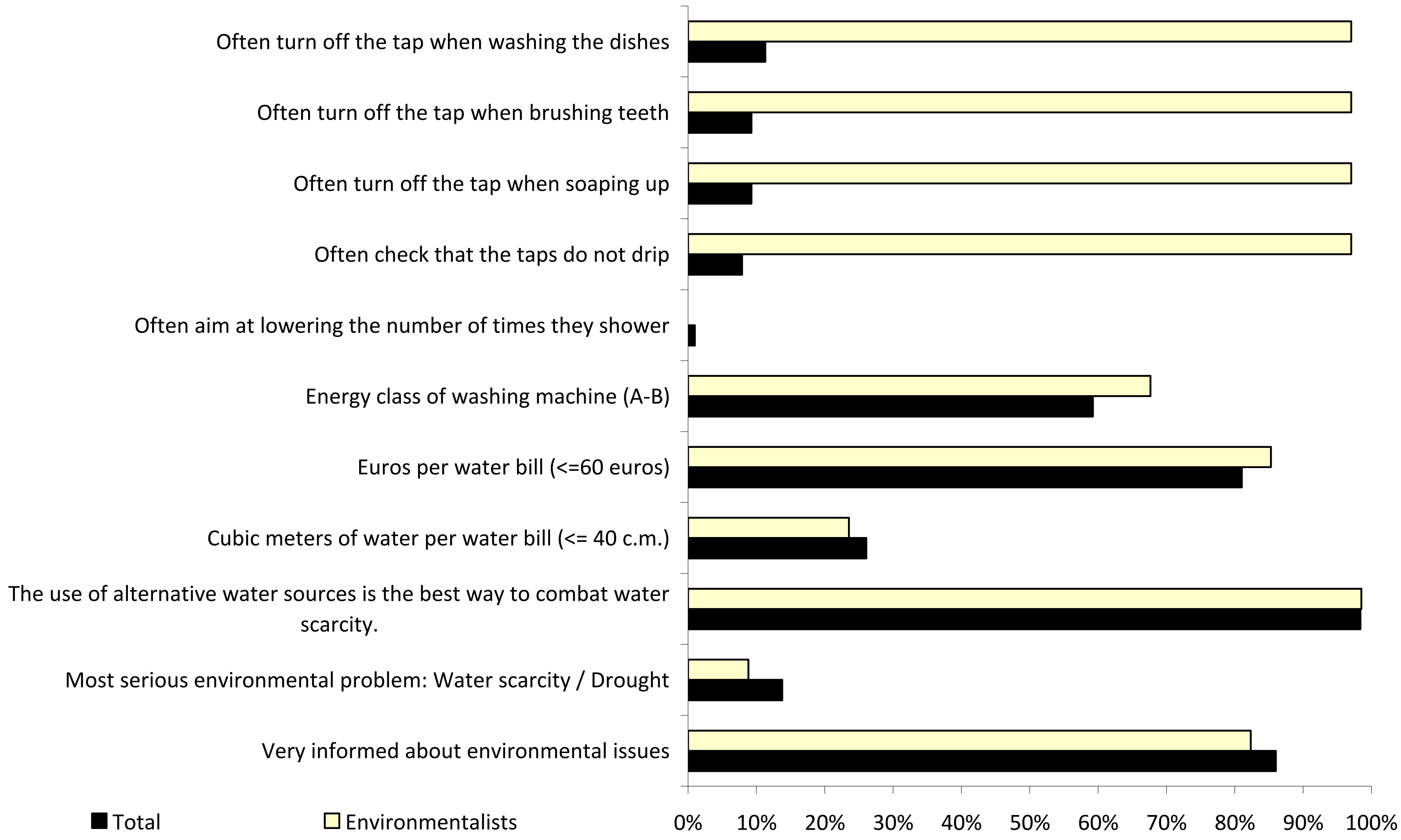


Figure 6-12 Combinational evaluation of certain attitudes and behaviours with high environmental consciousness.

6.3.2. Qualitative research results

A qualitative socio-psychological research of a panel of Athenian water users was held during 2013 (Gerakopoulou and Makropoulos 2013). The method used was that of biographical narrative (Elliot 2005) were the participants were asked open questions, based on a semi-structured interview schedule in order to lead the narration towards water demand behaviour and attitudes, water conservation and water saving technologies.

The combination of the conclusions of the phone survey and the qualitative social research method are presented next (published by Koutiva et al. 2015) to allow a more in depth understanding of the Athenians' water attitudes, perceptions, cognitions and attributions that explains their water related behaviours and decision making.

The phone survey results showed a high percentage of people reporting that they behave in a water saving manner. Simple conservation behaviours (such as closing the tap when brushing teeth, soaping and washing the dishes, checking often if taps are dripping etc) are adopted by the majority of the sample. However only a small fragment of the phone survey sample adopts wider water conservation behaviours such as limitation of daily showers and water saving technologies. Based on the qualitative research insight, this contradiction appears attributed to a cognitive misunderstanding which characterises the participants' representation on what "water saving" in everyday life means. It seems that the participants' account on water saving is limited to fairly stereotypical descriptions including only basic and general saving habits, such as checking and closing the taps.

Furthermore, it seems that the high moral value of water (e.g. representations related to the "preciousness" of water as a nature's source) enriches and, simultaneously, contradicts the positive self-image of those with high environmental consciousness. Even though participants have a strong intrinsic motivation towards saving behaviours in general, these positive attitudes are in conflict to more personal views and cultural beliefs such as: a) the perceived sufficient availability of water resources in Greece("nowadays there is no shortage of water in Greece", "water is everywhere", "it rains a lot" etc) and b) the existential and political value of water as a nature's resource ("water is joy, life, pleasure", "water should remain free" etc). Once more, the participants' positive attitudes towards water saving coincides with stereotypical behaviours of water saving such as "turn off the tap when I brush my teeth", but appear weakened when water use refers to more personal dimensions of water consumption such as relaxation, joy, irritation of the sensations etc.

Another example of such behaviours, monitored in the phone survey's results, is that the majority of the surveyed Athenians believe that they have decreased their showering time to a point that is non-discretional, a basic need, not possible to be decreased even more. This is also linked with a) the strong value of personal cleanliness and hygiene and b) the hedonistic dimension of water as a source of life and pleasure, and as such, labelled as a natural source which should remain free, unlimited and available to everyone.

An additional example, monitored in the results of the phone survey, is that Athenians know the amount of money they pay for water but ignore the amount of water that their bill accounts for. Based on the qualitative research's results, the difficulty to link water use with water's monetary value is attributed to the existential value (pleasure, source of life, etc.) and the ideological/political value (common good that should be free, cheap, democratic etc.) that prevail in their representations on water as a natural source.

6.3.3. Online survey's results

The online survey's main aim was to extract specific information regarding the water demand behaviour of households in Athens. It was decided to gather such information using an online survey since the time needed for completing the questionnaire was high, more than 30 min, making it almost impossible to use other means, such as phone or door to door, for answering the questionnaire. The questionnaire is presented in Annex III (in Greek) and its main sections are:

1. Environmental consciousness
2. Domestic water demand attitudes
3. Details of the water bill
4. In-house water appliances
5. Details of use of in-house water appliances and conservation
6. Factors influencing water conservation behaviour

The online survey was addressed to people that lived in Athens. The online questionnaire was published using the free online survey tool Survey Expression and a notification was sent using social media and email services to about 100 people living in Athens, out of which 88 filled out the questionnaire. From those that responded, 61 (70%) completed the entire questionnaire. 77% of the respondents were aged between 18-34 years old. The majority of was single (60%), had a high educational background (92%), lived in households with 2 or more members (77%), owned their house (65%) and lived in an apartment building (89%).

As seen in Figure 6-13, the majority of the participants consume less than 40 cubic meters of water and pay less than 40 euros per 3 months of water use.

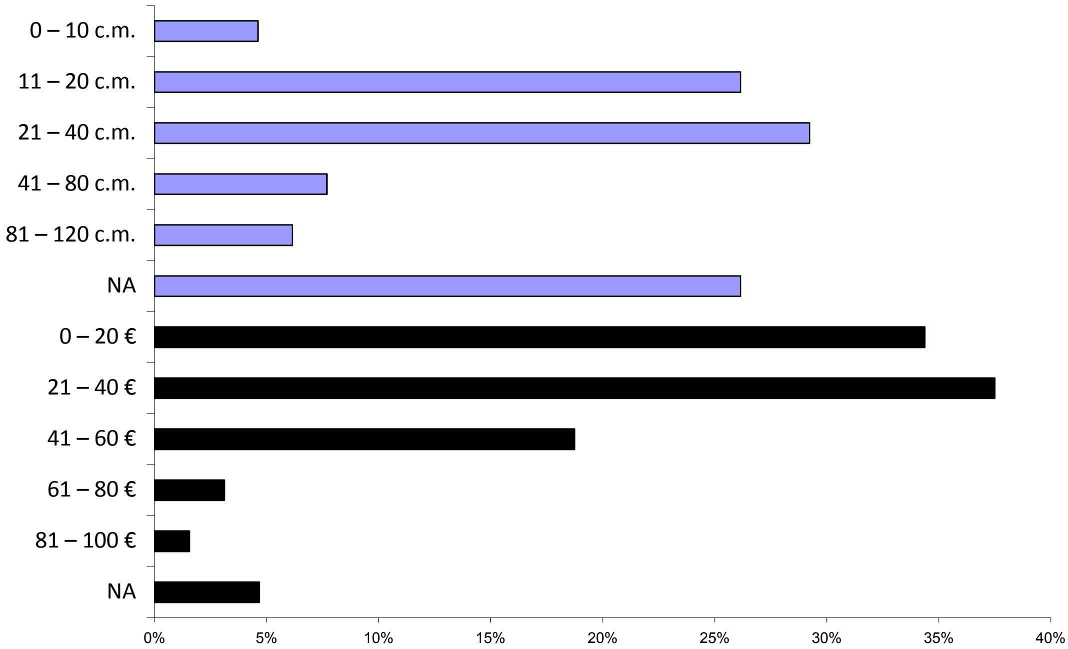


Figure 6-13 Cubic meters and euros that the online survey's participants consume and pay accordingly

Regarding environmental issues, the majority of the people indicated that they feel somewhat worried about the state of the environment, feel that they have an average environmental conscience and that they are somewhat informed regarding the state of the environment (Figure 6-13).

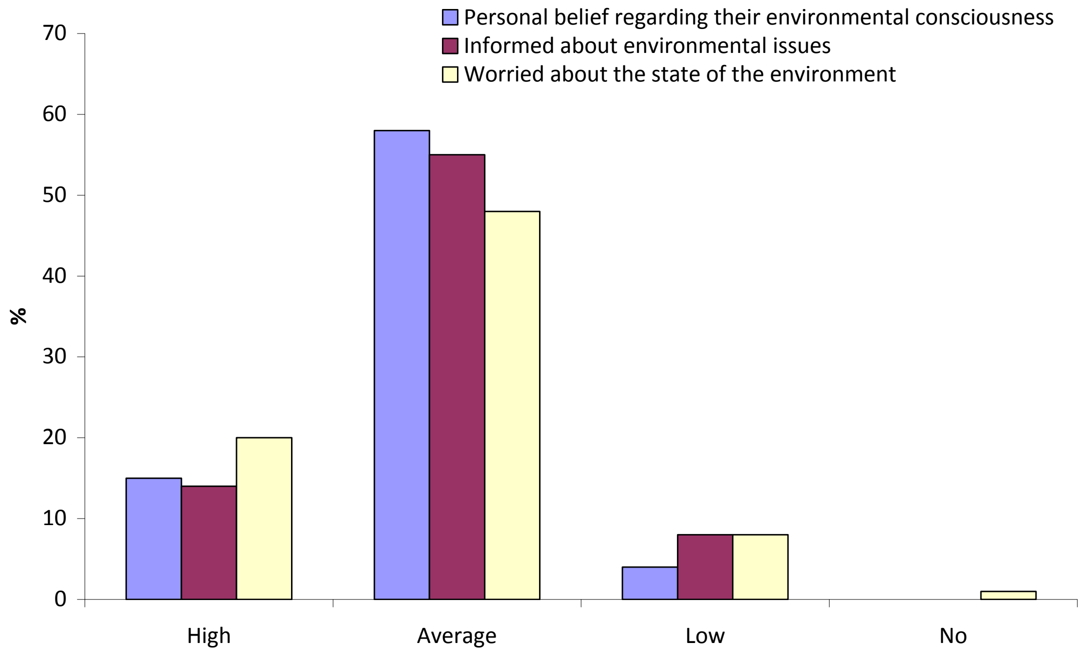


Figure 6-13 General beliefs regarding the personal environmental consciousness level, level of information and concern regarding environmental issues

In addition, only 11% of the sample scored as people with high environmental consciousness, receiving a score of more than 53.3 in the New Ecological Paradigm question.

The majority of the people that answered the survey (54%) scored as medium to high environmental consciousness in the New Ecological Paradigm scale (Figure 6-14).

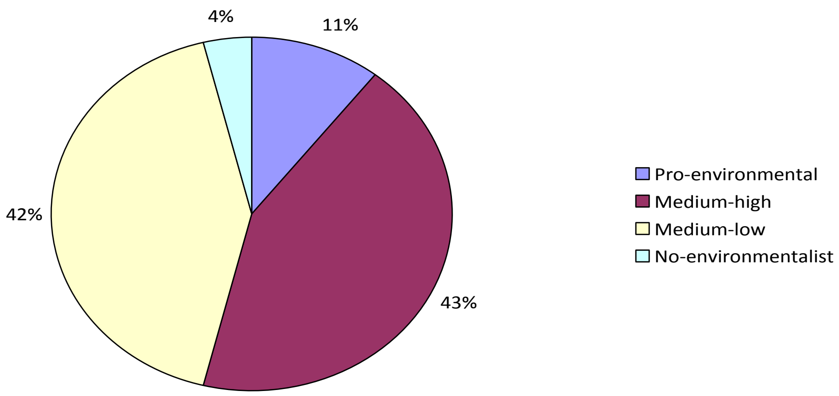


Figure 6-14 Environmental consciousness level based on the New Ecological Paradigm scale

The respondents gave answers that could be identified as positive towards water conservation. As depicted in Figure 6-15, the respondents may be characterised as having a high interest about water resources conservation, water scarcity reduction and willing to invest in water saving appliances.

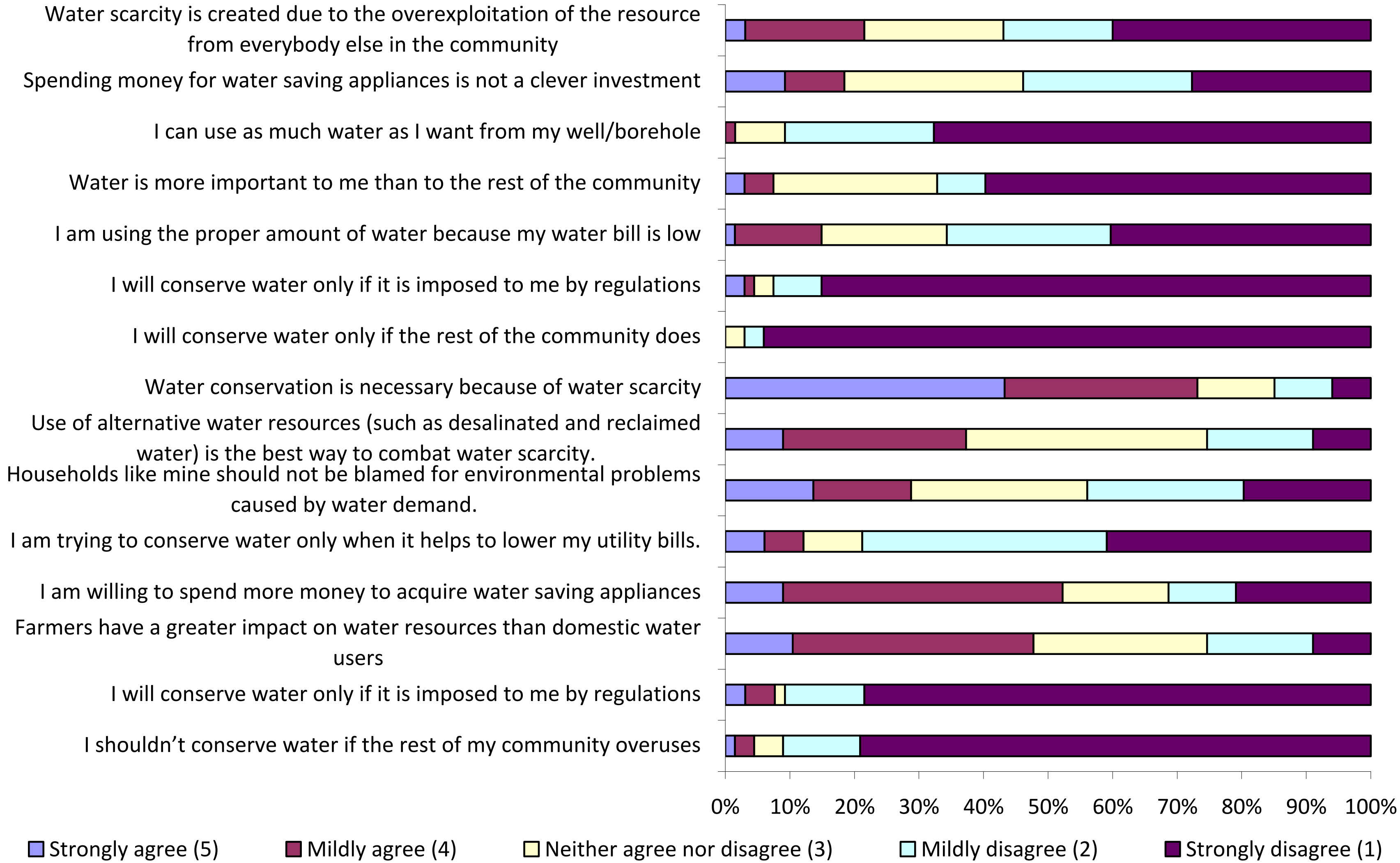


Figure 6-15 Attitudes towards water conservation

Figure 6-16 presents the most common in-house water appliances used by Athenian households that participated in the online survey. The majority of the installed appliances are not water efficient and therefore water conservation behaviour is mainly owed to the frequency of use of the appliances.

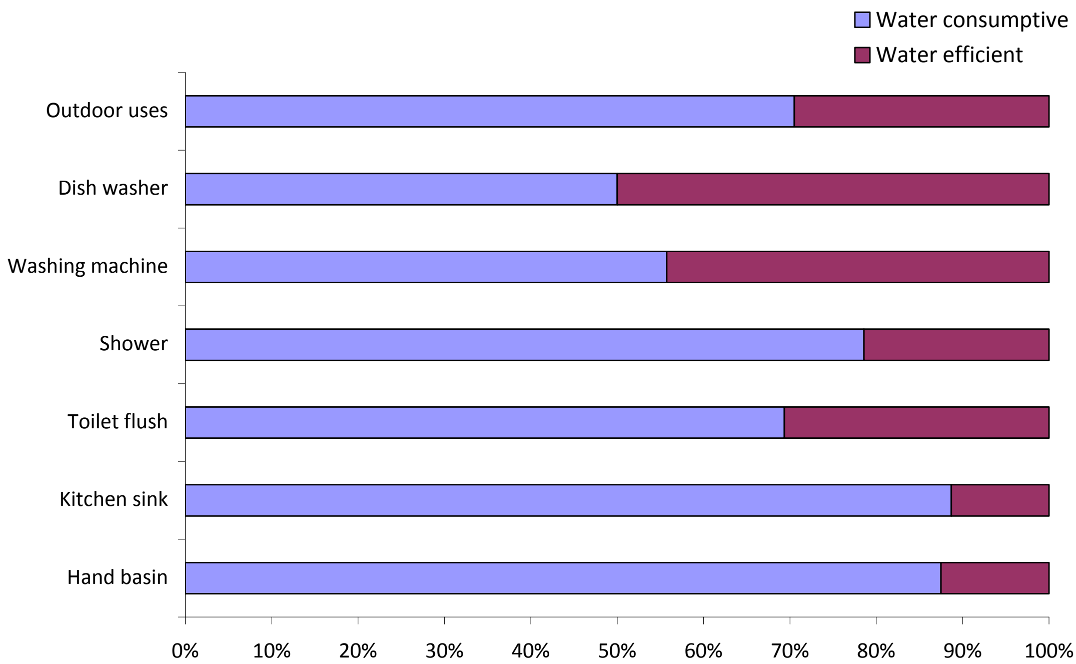


Figure 6-16 Results of questionnaire for in-house water appliances

Figure 6-17 presents the different frequencies of use for the in-house appliances that the participants reported. The survey was asking to report how many times the participants are using each household appliance and how many times they would use the appliance if they wanted to conserve water on a low or high level.

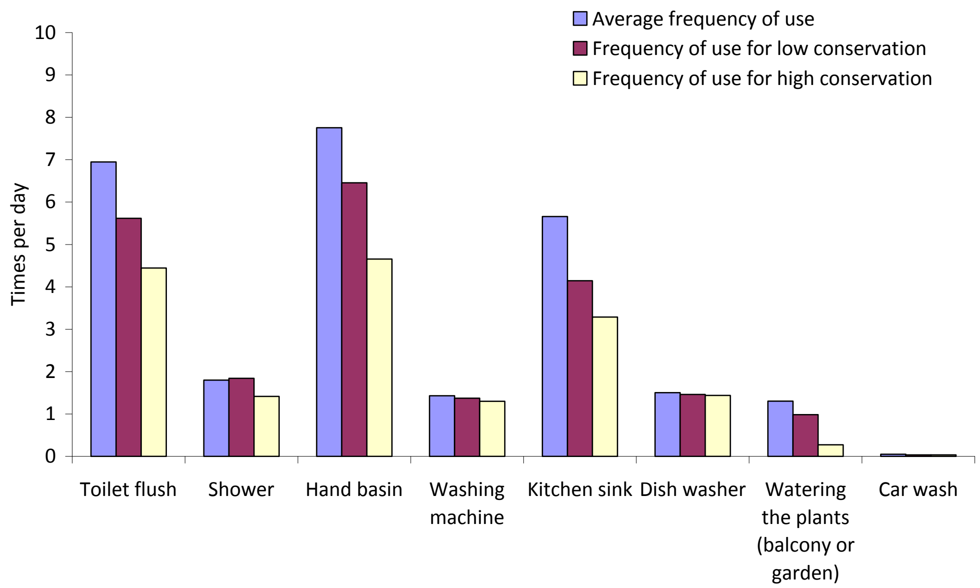


Figure 6-17 Frequencies of use for average water use and different water conservation levels

Figure 6-18 presents the participants answers regarding certain water conserving behaviours. The data shows that people are not willing to implement alternative technologies to decrease their water use because they feel that it is either expensive or difficult. Nevertheless, the participants have shown that they believe they act in a water saving way by turning off taps whenever they do not use water.

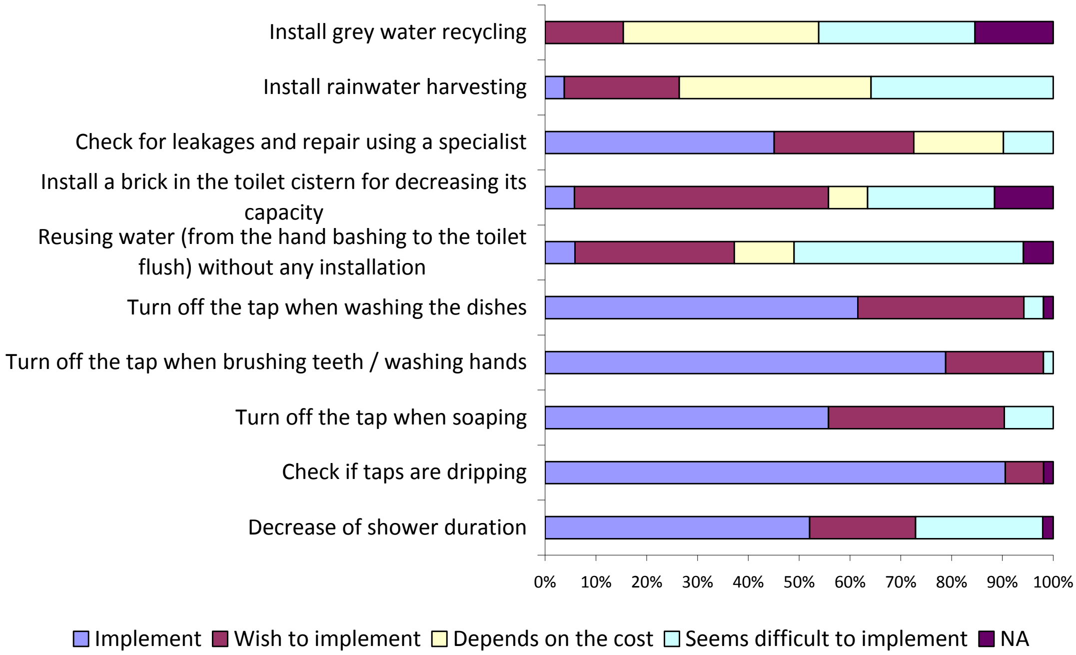


Figure 6-19 Potential household actions to conserve water

Finally, Figure 6-20 presents the degree that the participants are influenced by others, regarding water use. Almost all sources of influence present the same degree, with an exception of scientists and plumbers that seem to have a greater effect on water use behaviour.

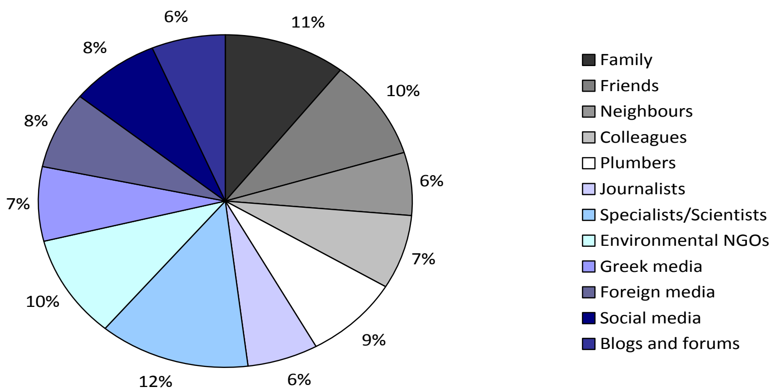


Figure 6-20 Degree of influence from various sources regarding water use behaviour

6.4. Socio-demographic data

In 1981 Athens had about 850.000 households which increased at about 1.000.000 households by 1991 and 1.350.000 households by 2001 and 1.850.000 by 2011 (Table 6-5) (ELSTAT, 2012). During the past 30 years there appears to have been an increase in the one and two member households and a major decrease in households with more than four members.

Table 6-5 Number of households and distribution of household members

Athens	ESYE census 1981		ESYE census 1991	
Household members	Number of Households	% Households	Number of Households	% Households
1	143750	17.02%	196233	19.12%
2	211800	25.08%	267604	26.07%
3	189240	22.41%	227513	22.17%
4	212280	25.13%	251564	24.51%
5	65860	7.80%	64699	6.30%
6	16630	1.97%	15030	1.46%
7	3790	0.45%	2531	0.25%
8	930	0.11%	766	0.07%
9	210	0.02%	219	0.02%
10	80	0.01%	175	0.02%
Total	844570	100.00%	1026334	100.00%
Athens	ESYE census 2001		ESYE census 2011	
Household members	Number of Households	% Households	Number of Households	% Households
1	297269	21.99%	416608	27.55%
2	368911	27.29%	431634	28.55%
3	297409	22.00%	313091	20.71%
4	283767	20.99%	267984	17.72%
5	73604	5.45%	60480	4.00%
6	21088	1.56%	15867	1.05%
7	5853	0.43%	4038	0.27%
8	2046	0.15%	1558	0.10%
9	801	0.06%	387	0.03%
10	869	0.06%	450	0.03%
Total	1351617	100.00%	1512097	100.00%

Figure 6-21 presents the evolution of immigrants within the Greek population for 1991, 2001 and 2011 based on the corresponding Censuses (ELSTAT, 2012). Unfortunately, up until 2001 Greek censuses explicitly failed to record all immigrants, with the 1991 Census significantly under-recording immigrant residents, finding only EU residents and those with legal status (Baldwin-Edwards et al., 2004). However, the 2001 Census, was able to record the majority of immigrants with fewer than 100.000 people not participating (Baldwin-Edwards et al., 2004).

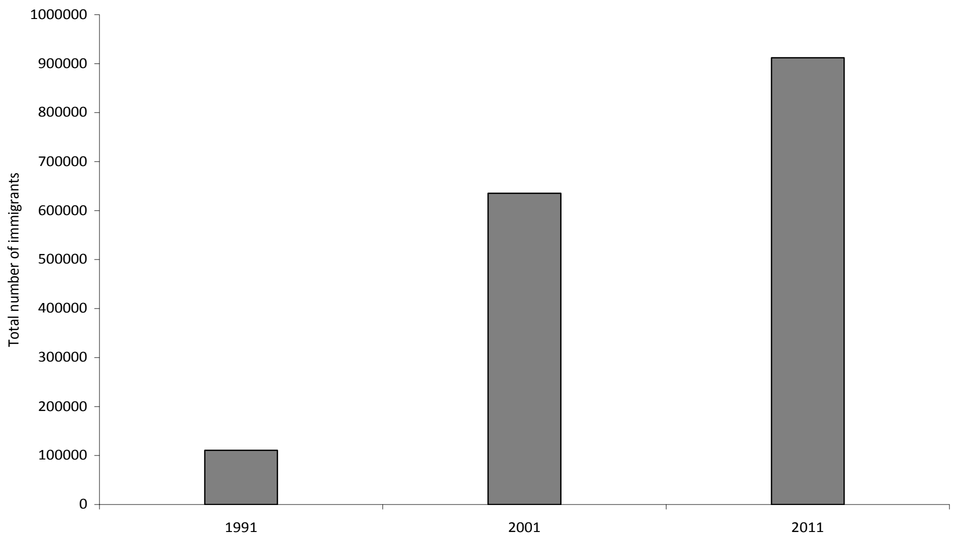


Figure 6-21 Evolution of immigrants within Greek population

The distributions of the socio-demographic characteristics of education level (Figure 6-22), age (Figure 6-23) and housing conditions (Figure 6-24), of the urban population of Athens are available from the National Statistical Office (ELSTAT, 2012). In addition to the information available from the Censuses there is a class categorization taking into account both income and occupation for 1981 and 1991 (Figure 6-25) (NCSR, 2006). It can be deducted from the following figures that the socioeconomic profile of the average Athenian household has not changed dramatically the past 30 years.

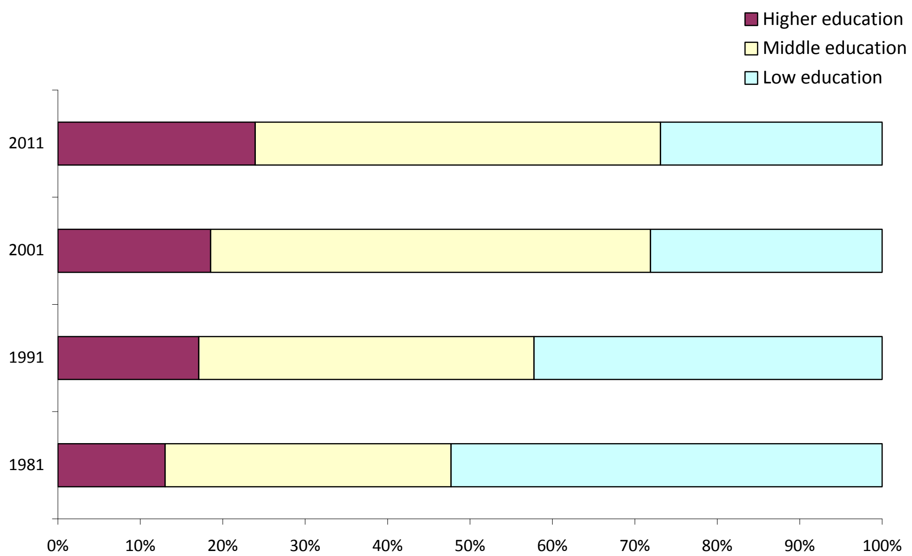


Figure 6-22 Distribution of education level based on 1981, 1991, 2001 and 2011 Censuses

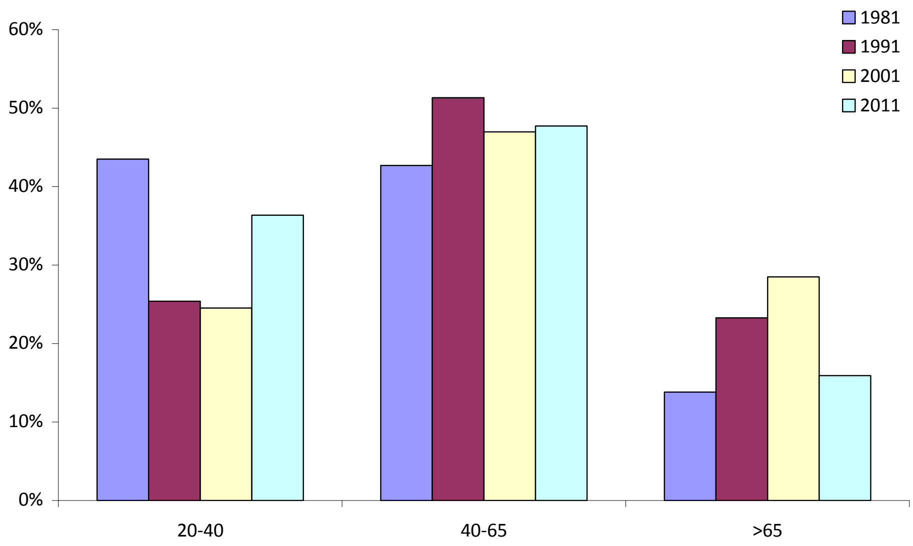


Figure 6-23 Distribution of age level based on 1981, 1991, 2001 and 2011 Censuses

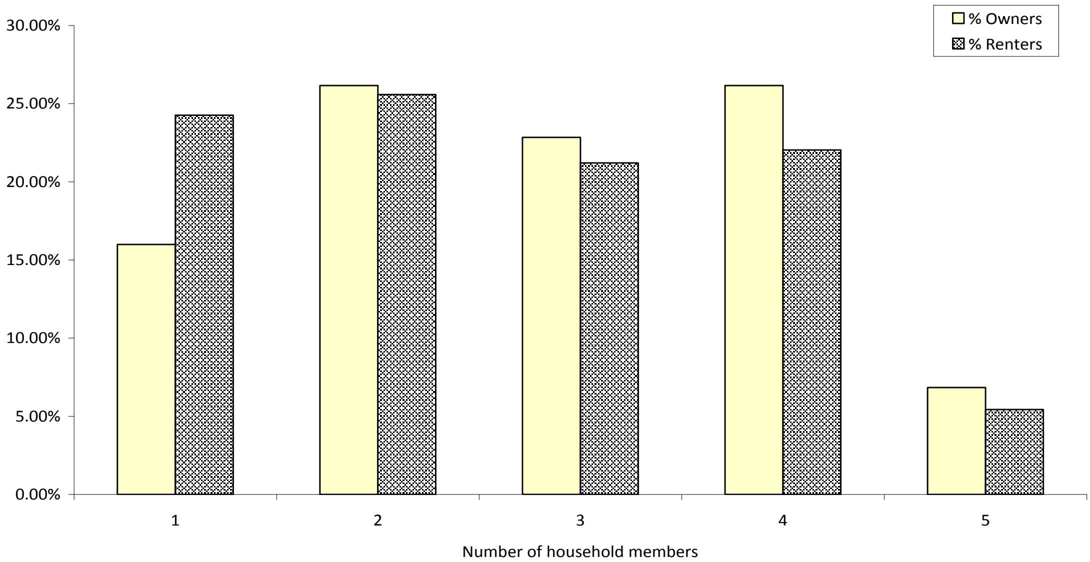


Figure 6-24 Distribution of housing conditions based on 1991 Census

Figure 6-25 Athens's population distribution of class levels and age (NCSR, 2006)

6.5. Conclusions

The lack of data regarding water attitudes and behaviour of the Athens' population required the design and application of two quantitative social research surveys. One basic result of these surveys is that the majority of the respondents reported that they act in a water saving way by checking taps for losses, by turning off taps when water flow is not directly used and by using their bathtub as a shower. Nevertheless, even though Athenians report by 54% that they have a medium to high level of environmental consciousness, they also report by 70% that they have negative attitudes towards water conservation and by 80% that they believe they have a small impact to water resources. These results may be explained as not just a discrepancy between attitudes and behaviours, if it is assumed that water saving behaviour has shifted in the minds of Athenians to behaviours with more impact, requiring more effort, rather than their everyday habits of turning off taps and not overusing water in the bathtub. It is possible to assume that water saving has become an intrinsic characteristic of the Athenian population that has been built probably from personal life experiences.

In other words, Athenians select to save water in stereotypical ways, but fail to decrease water uses that are associated with the "existential" and political dimensions of the representation on water consumption. The qualitative research showed how basic and sufficient water saving behaviours are attributed to the lasting effects of awareness campaigns and alarming experiences during the Athens' drought period of 1998-1994, that were embedded in culture, educating at that time young Athenians in adopting water saving behaviours. Nevertheless, there is a cognitive error that appears related to the past experience of drought and is amplified by a rationalisation mechanism: advance adoption of water saving habits (and especially of a nature that contradicts the existential and political dimensions of water consumption) are not perceived as urgent for Athenians, since there seems to be no immediate danger of drought in Greece, since, as they believe, water is everywhere and remains low priced.

Furthermore, the above results prove that even in the case of the Athenian population the attitudes towards water conservation are closely linked to the overall environmental consciousness. In the UWAB model this conclusion is utilised by assigning higher environmental consciousness to those household agents that were assigned (randomly) a positive attitude towards water conservation.

6.6. Summary

This Chapter presents all the data and information that were used for setting up the UWAB and UWOT models for the Athens urban water system. In particular, the urban water system of Athens was presented and namely its water supply and water demand dimensions, the drought period of 1988-1994 and the water demand management measures that resulted. Additionally, the results of the three social research methods that were applied in the Athens urban water system were presented in order to reveal water demand attitudes and their relation to actual behaviours and to recover details regarding the water demand behavioural rules of the Athenian household. Finally, the available socio-demographic data is presented, aiming at creating a descriptive image of Athens' population.

The following Chapter 7 presents the implementation of the proposed modelling platform to the Athens drought period of 1988-1994.

Chapter 7. Testing the modelling framework: The case study of the Athens 1988-1994 drought

7.1. Introduction

From 1988 to 1994 a persistent drought affected Athens' water supply. The main water demand management measures were the substantial increase of water prices, extensive water saving awareness campaigns in 1990, 1992 and 1993 and outdoor water restrictions in 1993 (EYDAP, 2009, Kanakoudis, 2008). In addition, the diversion of Evinos and the construction of the Evinos reservoir was decided in order to strengthen the water supply of the Mornos river that supplies water to Athens all the way form Western Greece.

The evolution of domestic water demand during the Athens 1988-1994 drought period will be used to test the efficiency of the developed modelling framework. This chapter presents the application of the framework to the Athens 1988-1994 drought period. The methodology proposed in Chapter 4 is used for setting up the UWAB and UWOT models and integrating their results.

In Chapter 4, the methodology of the proposed modelling platform was presented. In Chapter 5, the available information regarding the Athens urban water system were in turn presented. In this Chapter, the methodology is applied to the case of Athens 1988-1994 drought period. In order to investigate whether the model is able to capture the behaviour of the domestic water user under both normal and drought conditions, it was decided to investigate a larger period of time ranging from 1986 to 1998.

The results of the phone and online surveys were used to tackle the unavailability of data for the period under investigation. Due to the fact that the questionnaire was implemented in 2013 only the statistical analysis of the answers were used for setting up the modelling platform to investigate the case of Athens 1988-1994 drought period.

The following paragraphs present the procedures followed in order to setup and run the two models that compose the modelling platform and combine their results to estimate the water demand evolution of Athens population during the Athens 1988-1994 drought.

7.2. UWOT setup

UWOT's setup procedure for the simulation of the evolution of water demand for each water user type and water conservation level follows four distinct steps:

a. **Setup of the distribution of water demand categories:** Estimate a mean water demand per household and per water user type

b. **Setup of distribution of households' occupancy types:** Identify monthly household occupancy to include temporal effects of occupancy change (i.e. holidays)

c. **Setup of water demand trends:**

   1. Identify common household water consuming appliances

   2. Assign seasonal and annual trends and frequency of uses for the different water types

   3. Assign appliances' frequency of uses for the different water conservation levels

The following paragraphs present the implementation of the above steps for simulating the evolution of domestic water demean in Athens from 1986 to 1998, a timeframe that includes the drought period of 1988-1994

7.2.1. Setup of distribution of water demand categories

Three types of water users (low, average and high), were created in UWOT to simulate the evolution of Athens' domestic water demand. The average water user's baseline water demand per household was identified based on EYDAP's reported mean monthly domestic demand for 1986, which was 125 litres per person per day (EYDAP, 2009). The demand for the "low" and "high" water user types were estimated as follows:

1. It was assumed that monthly, domestic, per capita water demands follow a normal distribution.

2. Based on the fact that almost all of the area of the normal distribution's curve lies within 4 standard deviations from the mean ($\mu - 4\sigma$, $\mu + 4\sigma$)

3. It was identified that the minimum monthly water demand, assumed equal to EYDAP's minimum billed water volume, since 1996, of 2 cubic meters per month per water meter (EYDAP pricing policy data, 2013), translates to a volume of 67 ($\approx$ 66.66667) litres per person per day (with a minimum occupancy of 1 person per water meter). This was set to be equal to $\mu - 4\sigma$, with μ=125.

4. Hence it was calculated σ=15 ($\approx$ 14.58333) litres / person / day

In this research, it was assumed that average water users fall within one standard deviation of the mean (between –σ and +σ), corresponding to a 68.2% of the total population with a water demand of 125 litres per person per day. Low water users fall bellow one standard deviation of the mean (all those between –σ and -4σ), corresponding to a 15.9% of the total population with a water demand of 97 litres per person per day.

Finally, high water users fall above one standard deviation of the mean (all those between +σ and +4σ), corresponding to the remaining 15.9% of the total population with a water demand of 147 litres per person per day. The amount of domestic water demand for the high water user is reasonable when compared to the mean monthly domestic water demand of Athenian household in 2011. For example, the normal distribution, created above, estimates the highest water demand at around 185 litres per person per day which is comparable to the mean domestic water demand reported for high income suburbs of Kifisia, Marousi, Papagos in 2011.

The water demand for the low and high water user types were estimated by calculating the centre of mass of the surface created by the normal distribution's curve and the corresponding standard deviation line parallel to the y axis (Figure 7-1).

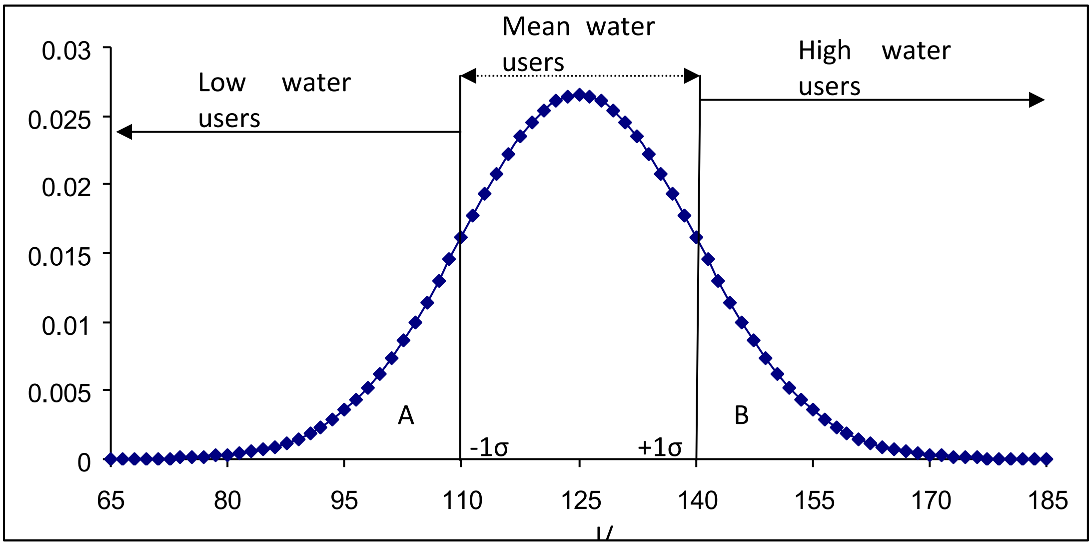


Figure 7-1 Normally distributed water demand of Athens population in 1986

The centre of mass of A and B with coordinates x_A, y_A and x_B, y_B may be estimated by using the following equations:

$A * x_A = MY(A)$ and $A * y_A = MX(A)$ Equation 7-1

$B * x_B = MY(B)$ and $B * y_B = MX(B)$ Equation 7-2

Where, as shown in Figure 7-1,

A is the area created by the normal distribution and the -σ vertical line

B is the area created by the normal distribution and the +σ vertical line

MY(A) is the y-axis momentum of the area A

MY(B) is the y-axis momentum of the area B

MX(A) is the x-axis momentum of the area A

MX(B) is the x-axis momentum of the area B

x_A, y_A are the coordinates of area A's centre of mass.

and x_B, y_B are the coordinates of the area B's centre of mass.

Consequently, Table 7-1 presents the setup parameters of the mean water demand of the different water user categories.

Table 7-1 Setup parameters of water demand categories

	Average water users	Low water users	High water users
Water users distribution	68.2%	15.9%	15.9%
Water demand (l/p/d)	125	97	147

The assumption that monthly, domestic, per capita water demands are normally distributed in the urban population was used to tackle the unavailability of data. The selection of normal distribution was made based on assumptions used by other domestic water demand studies that had either addressed the issue of unavailability of data by assuming that water demand follows a normal distribution (Espey et al., 1997) or that had estimated that in some cases water demand data follow a normal distribution (Surendran et al., 2005, Kashan, 2006). Nevertheless, researchers (Billings and Jones, 2011, Andey and Kelkar, 2009) have identified that domestic water demand does not follow a normal distribution but a log-normal distribution with an elongated tail. This non-normal distribution of domestic water demand is mainly attributed to the fact that there are households that consume so much more water than the average, due to high water consuming uses, such as pools and gardens, creating elongated tails (Butler and Memon, 2006). The normal distribution however is representative and thus the mean may be a useful magnitude for planning purposes (Morgenroth, 2014, Kashan, 2006). The implications of this assumptions in the modelling experiments results would be an underestimation of domestic water demand volumes.

7.2.2. Setup of distribution of households' occupancy types

The distribution of occupancy types for the household population is based on the Athens censuses of 1981 and 1991 (ELSTAT, 2012) (Table 7-2). The temporary reductions of urban population due to summer vacations is added by creating a predefined periodic fluctuation pattern where population of each household reduces to 92% and 95% of the maximum during the months of August and September respectively (Rozos and Makropoulos, 2013).

This fluctuation is imported to UWOT by inserting a .csv file that includes a time series of the monthly occupancy multiplier of 1, 0.92 or 0.95.

Table 7-2 Distribution of household occupancy types.

Number of household members	% households
1	17%
2	25%
3	22%
4	25%
5	10%

7.2.3. Setup of water demand trends

a. Identify common household water consuming appliances

The in-house water appliances for setting up UWOT for the common Athenian household were selected based on the results of the 2013 online survey and scientific literature (Rozos and Makropoulos, 2013). These in-house water appliances and their corresponding water consumption are:

- Conventional kitchen sink (KS) (consuming 10 litres per use based on Grant, 2006)
- Conventional hand basin (HB) (consuming 6 litres per use based on Grant, 2006)
- Conventional dish washer (DW) (consuming 35 litres per use based on EEA, 2001)
- Conventional toilet (T) (consuming 9 litres per use based on EEA, 2001)
- Conventional washing machine (WM) (consuming 100 litres per use based on EEA, 2001)
- Conventional shower head (SH) (consuming 60 litres per use based on Grant, 2006)
- Conventional 30 meter hose for outdoor uses (GA) (consuming 10 litres per use based on Grant, 2006)

Figure 7-2 illustrates the UWOT setup of a common Athens household.

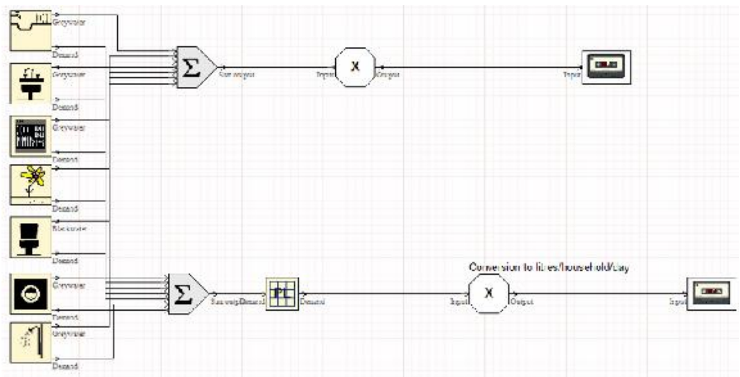


Figure 7-2 UWOT household setup for Athens

b. Assign seasonal and annual trends and frequencies of use of appliances per water user type

The seasonal variability and the frequencies of use of the household agents' appliances were based on those used in the study of Rozos and Makropoulos (2013) adjusted to reproduce the different mean monthly water demands of the selected water user types for 1986. Figure 7-3 presents water demand time series, resulted by simulating the monthly domestic water demand of 1986 in UWOT, for different water user types, in comparison to the mean monthly water demand of 1986 given by EYDAP's historical data. Figure 7-3 illustrates that there is a difference of the monthly distribution of domestic water demand, especially during the summer months. Nevertheless, the selected seasonal variations of appliance's use resulted in a good fit of the simulation of the Athens urban water system, as reported by Rozos and Makropoulos (2013), and thus it was decided to be used in this research as well.

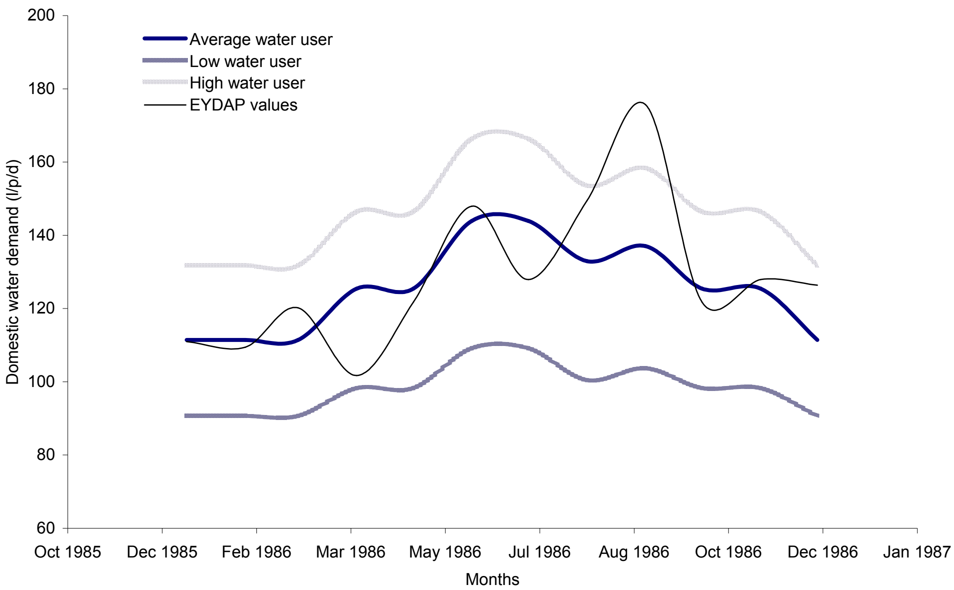


Figure 7-3 UWOT simulated monthly domestic water demand for different water user types and mean monthly water demand from EYDAP datasets for the year 1986.

The frequencies of uses for the different in-house appliances were assigned so as to result in the water demand of the different water user types defined in Table 7-1. Table 7-3, Table 7-4 and Table 7-5 present the selected frequencies of use for the in-house appliances for all water demand categories. Figure 7-4 presents an example of the time series of the frequency of use for the different appliances for the average Athenian water user.

Table 7-3 Frequencies of use for average water users

Appliance	Frequencies of use (mean daily)	J	F	M	A	M	J	J	A	S	O	N	D
KS	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
HB	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
DW	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
T	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94
WM	0.09	0.07	0.07	0.07	0.10	0.10	0.14	0.14	0.14	0.14	0.10	0.10	0.07
SH	0.42	0.31	0.31	0.31	0.44	0.44	0.61	0.61	0.61	0.61	0.44	0.44	0.31
GA	0.40	0.30	0.30	0.30	0.42	0.42	0.58	0.58	0.58	0.58	0.42	0.42	0.30

Table 7-4 Frequencies of use for low water users

Appliance	Frequencies of use (daily)	J	F	M	A	M	J	J	A	S	O	N	D
KS	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
HB	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
DW	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
T	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94
WM	0.05	0.04	0.04	0.04	0.05	0.05	0.07	0.07	0.07	0.07	0.05	0.05	0.04
SH	0.29	0.22	0.22	0.22	0.31	0.31	0.43	0.43	0.43	0.43	0.31	0.31	0.22
GA	0.03	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.02

Table 7-5 Frequencies of use for high water users

Appliance	Frequencies of use (daily)	J	F	M	A	M	J	J	A	S	O	N	D
KS	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
HB	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
DW	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
T	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94
WM	0.09	0.07	0.07	0.07	0.10	0.10	0.14	0.14	0.14	0.14	0.10	0.10	0.07
SH	0.48	0.36	0.36	0.36	0.50	0.50	0.69	0.69	0.69	0.69	0.50	0.50	0.36
GA	0.40	0.30	0.30	0.30	0.42	0.42	0.58	0.58	0.58	0.58	0.42	0.42	0.30

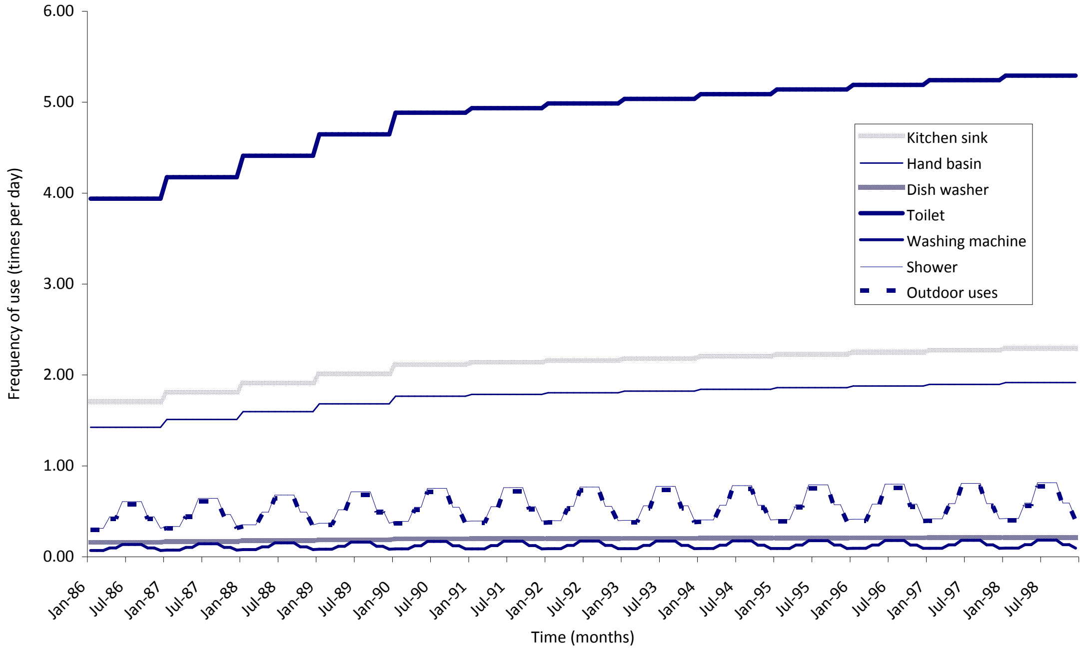


Figure 7-4 Example of frequency of use time series for different in-house appliances

As discussed in Chapter 5, Germanopoulos (1990) reported an annual increase of water demand of about 6% during the 1980s and projected that during the 1990s the annual increase would be much lower, approximately 1.30%, mainly due to the projected stabilisation of the quality of life conditions. The above water demand annual increase rates were translated into an increase of the frequency with which households are using each water consuming appliance. Figure 7-6 presents an example of this annual trend included in the frequency of use of shower heads of an average water user, which also includes the seasonal trend.

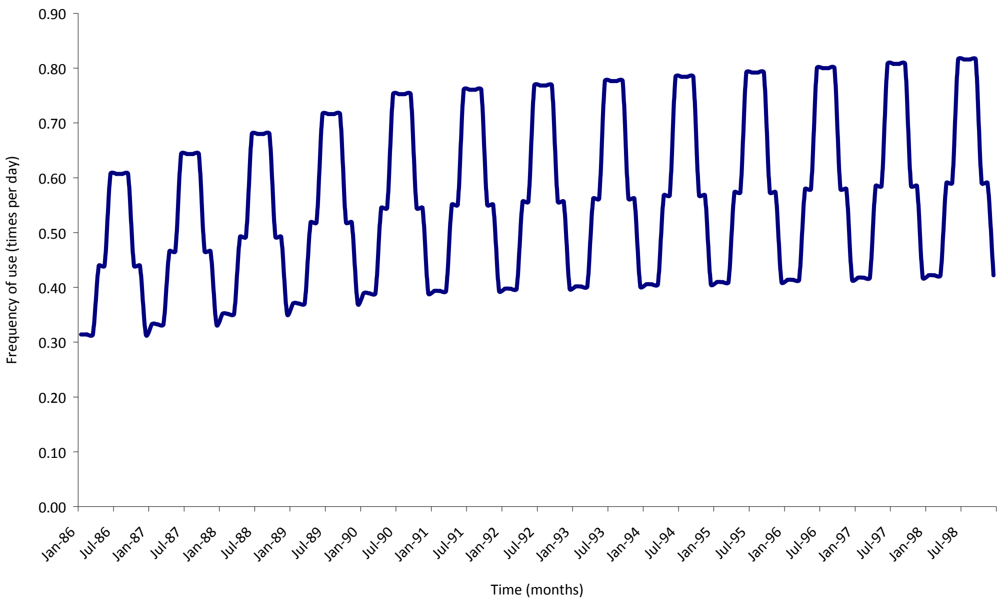


Figure 7-5 Shower head frequency of use for 1986-1998 including annual and seasonal trend

c. Assign appliances' frequency of uses for the different water conservation levels

In Chapter 6 the results of the three social research studies that were implemented during this research work were presented. Their results may describe the water demand attitude and perceived behaviour of the Athenian public in 2013. The main conclusions of these methods were that the Athenian water users hold a positive self-image characterised by a sufficient water saving habits based on stereotypical water efficiency behaviours (such as checking the taps) and choose to conserve water decreasing those water uses that they feel as discretionary or no mandatory while other water uses may be more consuming and have a higher water saving potential.

The different conservation levels were created by using the results of the online survey. A set of questions was included regarding the frequency of use of water appliances and the willingness and % of frequency decrease that was acceptable for different levels of water conservation. Since this social research was conducted in 2013, one cannot of course suggest that the replies are fully representative of customs in 1986, but in the absence of other data, these percentages of decrease for low and high conservation levels were utilised in setting up the appliances' frequencies of use for the different conservation levels (Figure 7-7) in our simulation. Different time series of frequencies of use were created for all the different water user types and their corresponding water conservation levels (average water user with low, high or no conservation level, low water user with low, high or no conservation level, high water user with low, high or no conservation level).

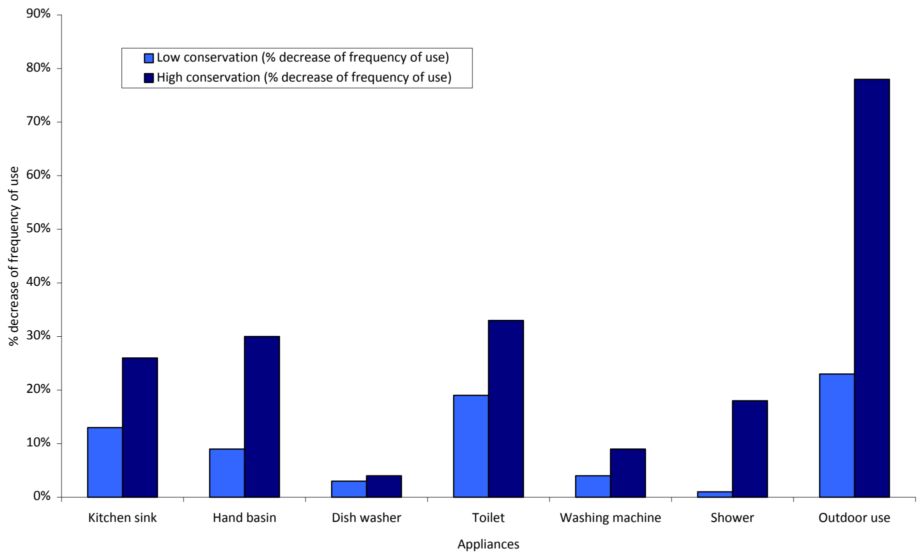


Figure 7-6 % change of frequency of use for different conservation levels based on the results of the online questionnaire

Table 7-6, Table 7-7 and Table 7-8 present both monthly and daily frequencies of use for in-house appliances for the different water conservation levels and for each water user type.

These values are the mean values of 1986, since the time series of monthly values for the period 1986-1998 include both seasonal and annual trends (these time series can be found in Annex IV). Furthermore, Figure 7-8 presents water demand for the different water demand types and for 1986. Finally, Figure 7-9 presents the percentage of decrease for each conservation level per water user category for 1986. The time series of all the frequencies of use of the in-house appliances for all the water demand types, conservation levels and occupancies can be found in Annex IV.

Table 7-6 Monthly and daily frequencies of use and change percentage for average water users and low and high conservation levels

			Average user Low conservation			
		Monthly			Daily	
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	51.21	6.66	44.56	1.71	0.13	1.49
HB	42.77	3.85	38.92	1.43	0.09	1.30
DW	4.78	0.14	4.64	0.16	0.03	0.15
T	118.16	22.45	95.71	3.94	0.19	3.19
WM	2.83	0.11	2.71	0.09	0.04	0.09
SH	12.56	0.13	12.43	0.42	0.01	0.41
GA	11.93	2.74	9.18	0.40	0.23	0.31
			Average user High conservation			
		Monthly			Daily	
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	51.21	13.32	37.90	1.71	26%	1.26
HB	42.77	12.83	29.94	1.43	30%	1.00
DW	4.78	0.19	4.59	0.16	4%	0.15
T	118.16	38.99	79.17	3.94	33%	2.64
WM	2.83	0.25	2.57	0.09	9%	0.09
SH	12.56	2.26	10.30	0.42	18%	0.34
GA	11.93	9.30	2.62	0.40	78%	0.09

Table 7-7 Monthly and daily frequencies of use and change percentage for low water users and low and high conservation levels

			Low user Low conservation			
		Monthly			Daily	
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	45.17	5.87	39.30	1.51	13%	1.31
HB	42.77	3.85	38.92	1.43	9%	1.30
DW	0.89	0.03	0.86	0.03	3%	0.03
T	118.16	22.45	95.71	3.94	19%	3.19
WM	1.51	0.06	1.45	0.05	4%	0.05

SH	8.81	0.09	8.72	0.29	1%	0.29
GA	0.77	0.18	0.59	0.03	23%	0.02

Low user High conservation						
	Monthly			Daily		
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	45.17	11.74	33.43	1.51	26%	1.11
HB	42.77	12.83	29.94	1.43	30%	1.00
DW	0.89	0.04	0.86	0.03	4%	0.03
T	118.16	38.99	79.17	3.94	33%	2.64
WM	1.51	0.14	1.37	0.05	9%	0.05
SH	8.81	1.59	7.23	0.29	18%	0.24
GA	0.77	0.60	0.17	0.03	78%	0.01

Table 7-8 Monthly and daily frequencies of use and change percentage for high water users and low and high conservation levels

High user Low conservation						
	Monthly			Daily		
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	57.84	7.52	50.32	1.93	13%	1.68
HB	58.71	5.28	53.42	1.96	9%	1.78
DW	4.78	0.14	4.64	0.16	3%	0.15
T	148.06	28.13	119.93	4.94	19%	4.00
WM	2.83	0.11	2.71	0.09	4%	0.09
SH	14.29	0.14	14.15	0.48	1%	0.47
GA	11.93	2.74	9.18	0.40	23%	0.31

High user High conservation						
	Monthly			Daily		
Appliance	Original frequencies of use	Frequencies decrease	Frequencies of use	Original frequencies of use	% change (online survey)	Frequencies of use
KS	57.84	15.04	42.80	1.93	26%	1.43
HB	58.71	17.61	41.09	1.96	30%	1.37
DW	4.78	0.19	4.59	0.16	4%	0.15
T	148.06	48.86	99.20	4.94	33%	3.31
WM	2.83	0.25	2.57	0.09	9%	0.09
SH	14.29	2.57	11.72	0.48	18%	0.39
GA	11.93	9.30	2.62	0.40	78%	0.09

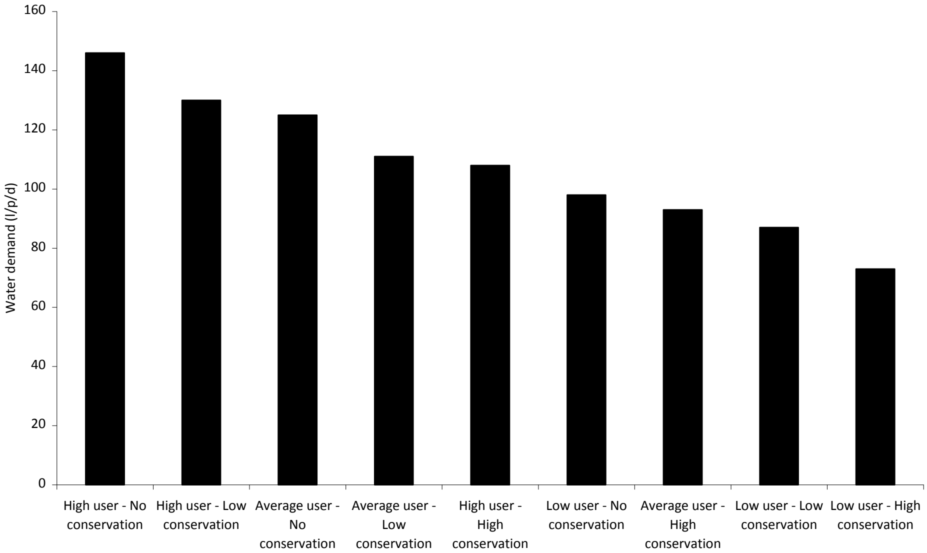


Figure 7-7 Water demand per water user category and conservation level for 1986

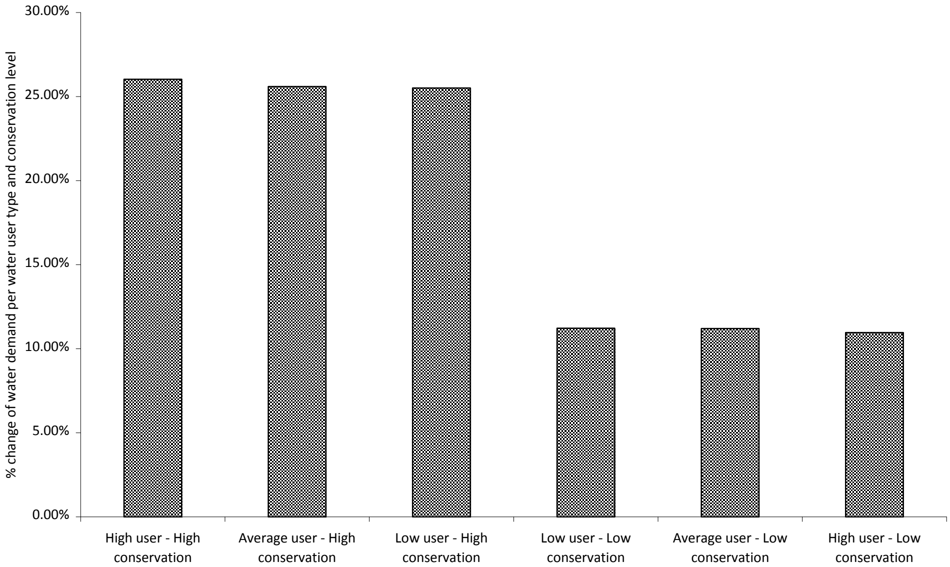


Figure 7-8 Percentage of change of water demand per water user type and conservation level

7.3. UWOT simulation

Following the setup of the household appliances' frequencies of use for each water demand type and conservation level, UWOT was set to run from 1986 to 1998 on a monthly basis (a total of 156 time steps). An example of the results of UWOT is given in Figure 7-9 for households with average water user type per conservation level. These results were used firstly to estimate the water bills per household demand type and secondly to be integrated with the UWAB results to estimate the total mean monthly water demand of Athens population during the period of 1986-1998.

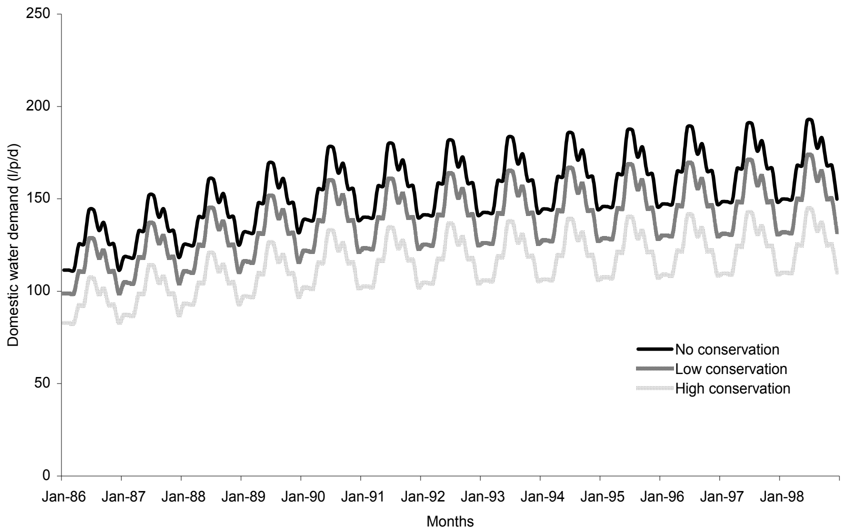


Figure 7-9 Water demand in l/p/d for average water users and no, low and high conservation level

7.4. UWOT – UWAB connection: estimating water bills per household demand category

The results of UWOT were used to estimate the water bills that Athens' households receive based on their different water demand types as the simulation progresses. The estimated water bills are available to the household agents every 3 months matching the billing period of EYDAP S.A..

In order to estimate the quarterly water bills sent by EYDAP to Athens' households, the water tariffs for the relevant period were acquired (Chapter 6 Table 6-5) (EYDAP pricing policy data, 2013). The estimation of quarterly water bills for different water demand types, occupancies and conservation levels was then communicated to the UWAB model (through a CSV file).

7.5. UWAB setup

The implementation of the designed modelling platform to Athens drought period requires the parameterisation of the model to depict the social situation of Athens in the late 80s and 90s. The following paragraphs explain the parameterisation process as well as the sources used for setting up UWAB.

7.5.1. Setup of Athens household agents

In 1981 Athens had about 850.000 households which increased to about 1.000.000 households by 1991 (ELSTAT, 2012). Since it is impractical in terms of simulation processing time to create about 1.000.000 agents and simulate their behaviour, it was decided to aggregate the households with one household agent representing 1000 households with the same preferences and characteristics (scaling down ratio = 0.001).

Due to computing limitations it was necessary to scale down the population for the simulation. Such scaling down is not uncommon in water use related agent based models.

For example, Galan et al. (2009) created 12500 agents for simulating 125000 families (scaling down ratio = 0.1), Becu et al. (2003) created 325 agents for simulating 2500 farmers (scaling down ratio = 0.13), Athanasiadis et al. (2005), used 100 cellular automata for simulating more than a million of domestic water users (scaling down ratio = 0.0001) and finally, Barthel et al. (2008) created 50000 agents for simulating a total of 10.8 millions of inhabitants of the upper Danube catchment (scaling down ratio = 0.005).

Consequently, in UWAB model, the simulation begins with 930 household agents representing the 930.000 households of Athens. Every twelve steps (i.e. every year with a time step being one month) 25 new household agents, representing 25.000 households, are created to demonstrate the population increase that took place from 1986 to 1998.

The personal variables that need to be set during the UWAB setup are the socio-demographic and the social impact characteristics. These variables characterise the population and remain constant throughout the simulation. Household agents are assigned levels of socio-demographic characteristics consistent with socio-demographic characteristics distribution within the population reported by the Office of National Statistics (ELSTAT, 2012). These include characteristics of education level, age and housing conditions. In addition, an income class categorization was used taking into account both income and occupation (NCSR, 2006).

7.5.2. Water demand policies setup

The effect of the water price changes is usually evaluated using an econometric approach (see Mylopoulos et al., 2004) which can be combined with an ABM approach for evaluating water pricing policies (see Athanasiadis et al., 2005). In this work, UWAB captures the effect of the information that water price changes and not the effect of the actual change in price. This is because the UWAB model tries to capture the changes in attitudes and perceptions and their translation to water demand behaviour. It was obvious while exploring the Athens urban water system and the drought period of 1988-1994 that even though water prices remained high after the drought period the water consumption increased. This instance allows us to identify awareness raising campaigns and the drought conditions more important in changing attitudes and behaviours of domestic water demand. For this reason, pricing policy is set as an external positive or negative force towards water conservation affecting the social impact exerted on the household agents. An increase or decrease of the water price is assumed to affect the population by adding an external influence parameter (positive or negative respectively) towards water conservation.

From 1986 to 1998, water prices changed eight times, either as a correction of the water price levels (prior to 1990 and after 1993), or as a policy measure directly targeting the issue of the drought during the period 1988-1994 (EYDAP, 2009). The transmission of this information is assumed to start one month prior to the application of the water price change and to keep on affecting the household agent for the next five months, leading to a total of a six months “information effect period” for all price changes. EYDAP records suggest that water prices changed in the following months: 01/07/1986, 01/07/1988, 0101/1990, 01/05/1990, 01/01/1991, 01/01/1992, 01/07/1992 and 01/12/1995.

The variables of water saving awareness campaigns that need to be set are the influence strength (S_{AC}) and the implementation period. The influence strength of a water saving awareness campaign is an experimental variable and was set during the calibration process of the model. There were in all three periods of water saving awareness campaigns for the case in question [01/01/1990 – 31/12/1990], [01/01/1992 – 31/12/1992] and [01/01/1993 – 31/12/1993] (EYDAP, 2009, Kanakoudis, 2008) and these were modelled in this work.

A drought variable is included in the UWAB model indicating whether or not there is a drought event and the information is assumed to affect all of the population. In this case, the drought variable's parameterisation coincides with the awareness raising campaigns. This assumption is based on the fact that it is almost impossible for everyone to know that there is a drought, and thus this variable follows the information sent from the state regarding the state of water resources. It is assumed that drought conditions are felt by the population as severe (drought_effect = 2) from 1990 to middle 1992 and as mild (drought_effect = 1) from 1992 until the end of 1994.

During 1993 authorities increased their efforts to reduce domestic water demand as much as possible. On top of awareness campaigns and water price increases a series of water use restrictions to outside uses and penalties to heavy water users were also introduced (Kanakoudis, 2008). These extra water policies drastically affected Athenians, resulting in a 52% reduction of mean monthly water demand, compared with the expected one (Kanakoudis, 2008). These extra water policies are introduced as two extra dummy parameters that are added to the behavioural intention functions of the water conservation levels during 1993. These dummy parameters increase the probability for high and low water conservation level, thus increasing the behavioural intention of the household and ultimately the probability to conserve water.

7.6. UWAB simulation

Following the setup of the household agents, UWAB is ready to simulate the behaviour of Athens' household agents for 156 months from 1986 to 1998. UWAB results come in the form of number of household agents per water user category and conservation level (Figure 7-10). The effect of both the awareness raising campaigns and the water price changes is evident in Figure 7-10. During 1990, 1992 and 1993 there is a significant behaviour change towards water conservation for all three water user types.

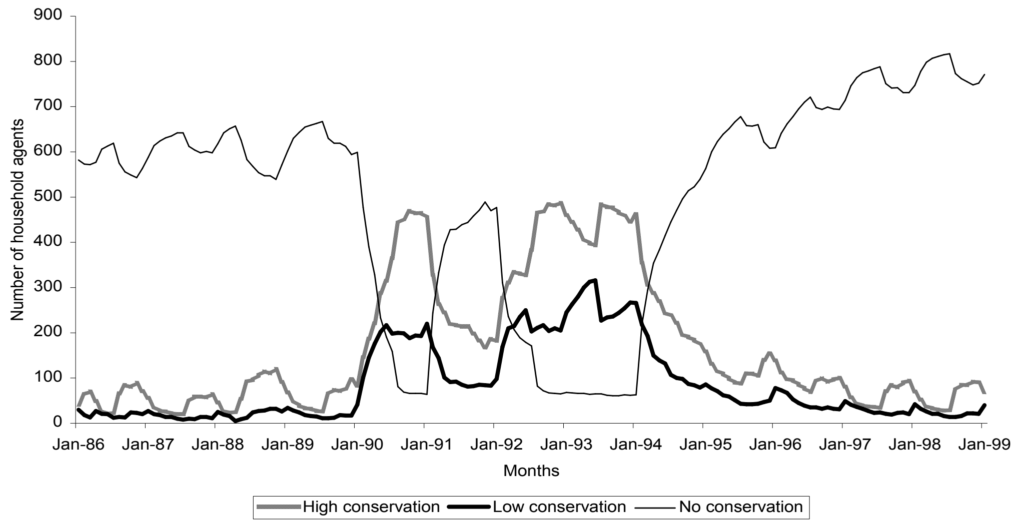


Figure 7-10 Example of UWAB's results, as time series of number of household agents that are average water users and perform no, low or high level of water conservation

7.7. Validation of the UWAB – UWOT modelling platform

Agent based model validation is a notoriously difficult task since ABMs are complex due to the high number of agents, states and interactions and due to the fact that usually ABMs are built to explore previously unknown emergent patterns (Nikolic et al., 2013). The following paragraphs present experiments where each one of the experimental global variables is altered while the rest remain constant. The purpose of these experiments is to test the "logical" evolution of the simulation. The evolution of the positive and negative attitudes within the population of the household agents is used to check UWAB. It is expected that during the months with water demand management strategies in place the percentage of positive attitudes increases.

The Behaviour Space tool of NetLogo was used to assign values, number of repetitions, and stopping criteria. Each experiment run for 100 repetitions and the presented results are the mean value of the 100 runs. The constant values of the experimental variables are given in Table 7-9. For each experiment only the value of the experimental variable under investigation is changed.

Table 7-9 Constant values for experimental variables

Experimental variable	Constant value
Initial percentage of positive attitudes towards water conservation	15%
External positive impact towards water conservation	15%
Volatility of social impact	15
Mean strength of influence	5
Social network structure	Free-scale structure
Mean strength of awareness raising campaigns	23
Mean strength of price changes	5
Transmission time of price change information	3

7.7.1. Volatility of social impact (T)

Two experiments were performed to verify UWAB's behaviour in terms of the Volatility of Social Impact (T) experimental variable. The first experiment had a very low value while the second one had a very high value of Volatility of Social Impact. From Figure 7-11 it is suggested that when volatility of social impact increases the impact of water demand management policies is decreased. This is an expected behaviour of the model since, as stated in Chapter 2, high values of volatility of social impact mean that attitudes are difficult to change and low values that attitudes are highly dependent on social norms (Wragg, 2006).

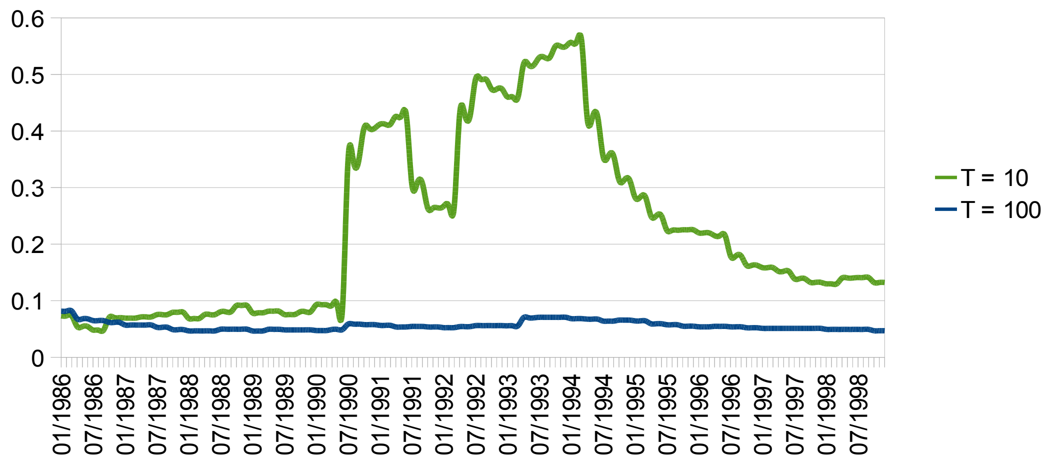


Figure 7-11 Evolution of positive attitude towards water conservation for two different values of volatility of social impact (T = 10 and T = 100)

7.7.2. Initial positive attitudes (%ipa)

The behaviour of UWAB in respect of the Initial Positive Attitudes (ipa) experimental variable was tested by setting up three experiments with ipa equal to 0%, 50% and 100% (ipa=0, ipa=0.5 and ipa = 1). Figure 7-12 presents the evolution of positive attitudes towards water conservation for the three different values of initial positive attitude percentage. Changing the initial percentage of positive attitudes does not alter significantly the evolution of positive attitudes in the months when awareness raising campaigns are in place. This is mainly attributed to the fact that ipa variable was created to define the attitude of the household agents at t=0 that evolves based on the Conservation behaviour procedure (see Chapter 4) depending on several factors. In addition, household-agent's tend to change their attitude based on their personal preferences and the social impact exerted to them, irrespective of their initial attitude set by the model. This phenomenon is illustrated in Figure 7-12, during the first months of the simulation, where the percentage of positive attitudes decreases significantly for initial positive attitudes of 100% or increases significantly for initial positive attitudes of 0%. In any case, the evolution of the positive attitudes follows the implemented water demand management strategy.

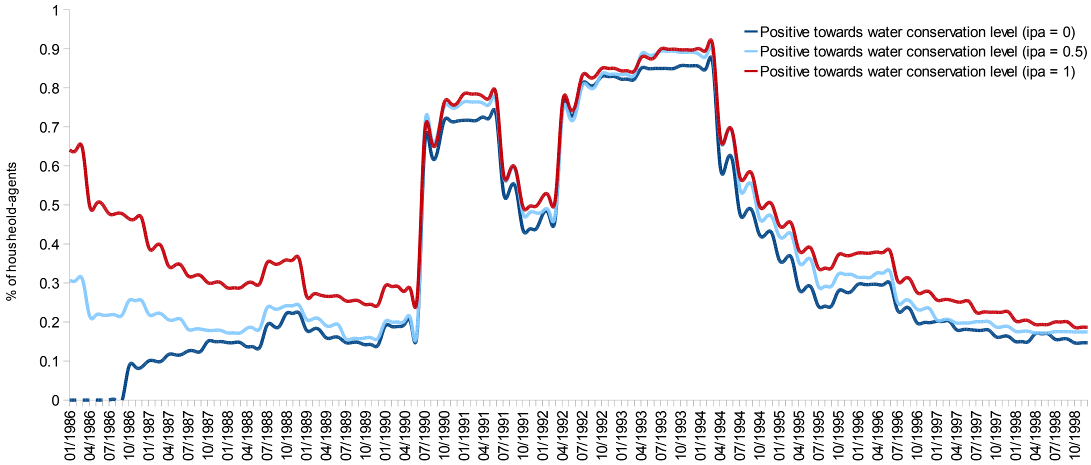


Figure 7-12 Evolution of positive attitude towards water conservation for three different values of initial positive attitude percentage (%ipa=0, %ipa=0.5 and %ipa = 1)

7.7.3. External social influence (%epa)

The behaviour of UWAB with respect to the External Positive Impact (epa) experimental variable was tested by setting up three experiments with epa equal to 0%, 50% and 100%. Figure 7-13 presents the evolution of positive attitudes towards water conservation for three different values of external positive impact percentage (%epa=0, %epa=0.5 and %epa = 1). UWAB behaves as expected when altering the percentage of the household-agent population that receives an external positive impact following the implemented water demand management strategy. UWAB's results alter showing the effect of the epa experimental variable. The higher the effect, the more household agents have a positive attitude towards water conservation. This is mainly attributed to the fact that the household agents receive an extra impact from a positive attitude.

In addition, as presented in Figure 7-14, the water conservation behaviour is affected widely by the epa experimental variable. This effect could be attributed in the fact that the household agents' behaviour depends on their attitude and therefore the effect on the attitude is mirrored to the water conservation behaviour. In any case, the evolution of the positive attitudes is verifiable when changing the percentage of household agents that receive an external positive impact.

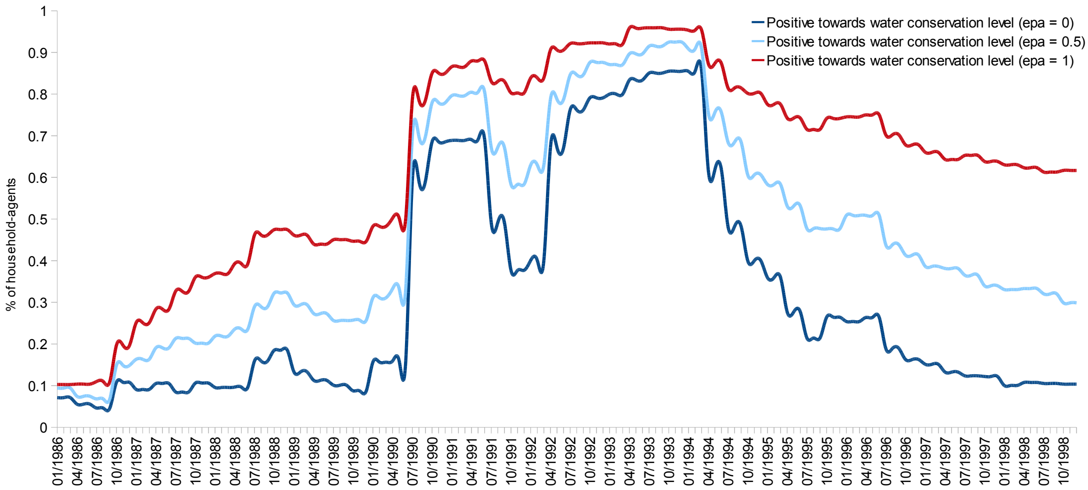


Figure 7-13 Evolution of positive attitude towards water conservation for three different values of external positive impact percentage (%epa=0, %epa=0.5 and %epa = 1)

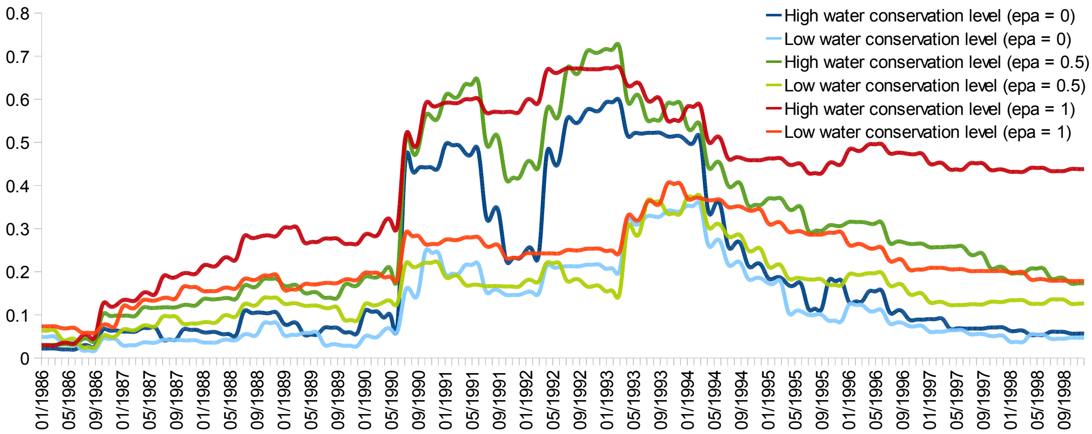


Figure 7-14 Evolution of high and low water conservation behaviours for three different values of external positive impact percentage (%epa=0, %epa=0.5 and %epa = 1)

7.7.4. Social Network's structure

Two alternative network structures were assessed based on their ability to allow water conservation attitudes to evolve within the social network under investigation. The main properties and characteristics of these two structures are given in Chapter 2. Both of the network structures result in a reasonable evolution of positive attitudes, following the water demand management strategy (Figure 7-15). During the sensitivity analysis process these two complex network structures will be assessed based on their ability to represent the way positive attitudes were diffused during the Athens drought and demand management strategies implementation period of 1988-1994.

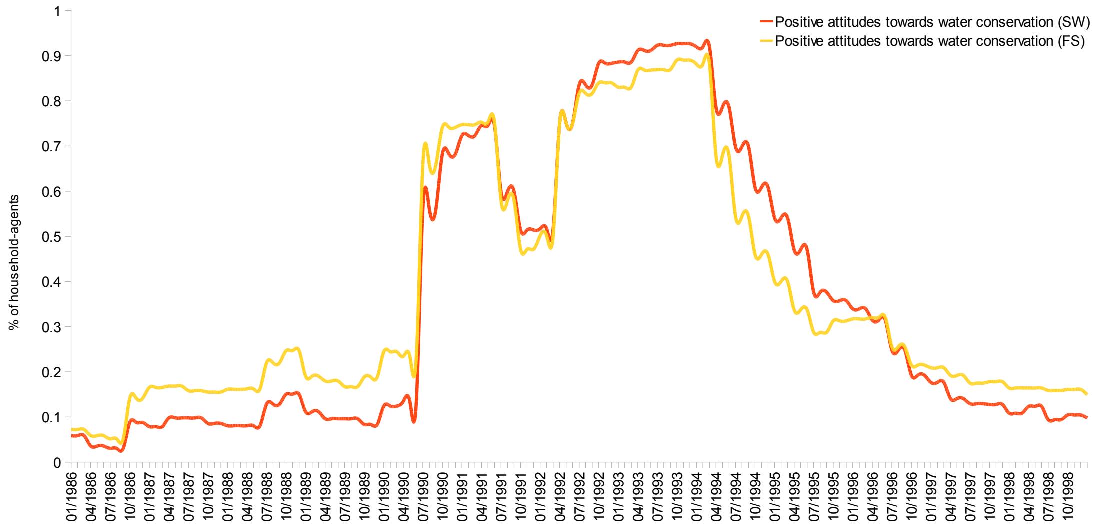


Figure 7-15 Evolution of positive attitude towards water conservation for two different network structures (small world (SW), free scale (FS))

7.7.5. Mean strength of influence (S)

UWAB's behaviour with respect to the mean strength of influence (S) experimental variable was checked by performing experiments for values ranging from 0 to 100. Figure 7-16 presents the results for 6 values 0, 2, 5, 10, 20 and 30. As is presented in Figure 7-16, high values of S decrease the effect of the water demand management strategies to the water conservation attitude of the household agents. This phenomenon is due to the fact that as the mean strength of influence of the population increases so is the difficulty to influence one another. This is because every household agent samples the value of its personal strength of influence from the normal distribution that is created using as a mean the mean strength of influence with a coefficient of variation equal to 0.8. As the mean value increases but the standard deviation remains 0.8 the difference between the strength of influence of the interacting agents decrease and thus their ability to influence one another. The distributions have all the same variability since they share the same coefficient of variation. It is evident from Figure 7-16, that UWAB's results from all the different values of mean strength of influence verify the model's behaviour illustrating the effects of the water demand management strategies.

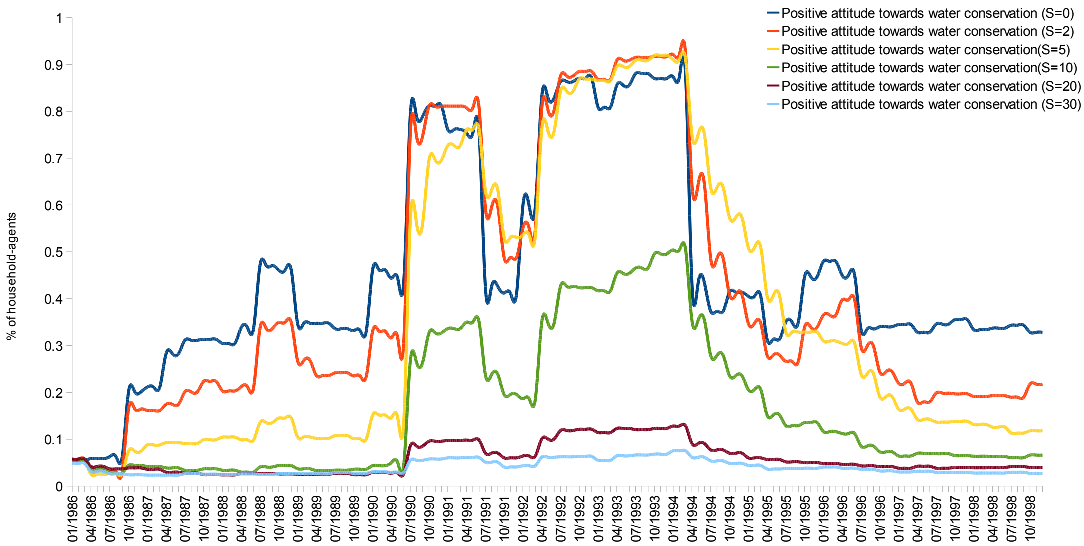


Figure 7-16 Evolution of positive attitude towards water conservation for six different values of mean strength of influence (S=0, S=2, S=5 ,S=10, S=20 and S = 30)

7.7.6. Influence strength for water saving awareness (S_{AC})

The evolution of positive attitudes is affected by the influence strength of the water saving awareness raising campaigns. The higher the value of the Sac is, the higher is the effect of the water saving campaign (Figure 7-17). This is an expected behaviour of the model, since this experimental variable was designed to portray the “power” that the water saving campaign has towards changing the attitude of the household agents population.

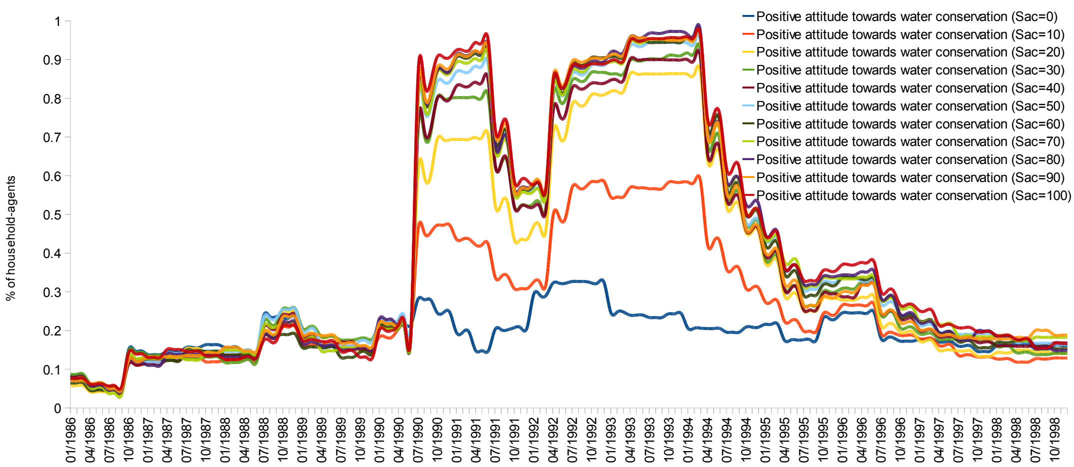


Figure 7-17 Evolution of positive attitude towards water conservation for eleven different values of awareness raising campaign's strength of influence (Sac=0, Sac=10, Sac=20 ,Sac=30, Sac=40, Sac=50, Sac=60, Sac=70, Sac=80, Sac=90 and Sac= 100)

7.7.7. Influence strength for water pricing (S_{PC})

The evolution of positive attitudes is affected by the influence strength of the water price changes. The higher the value of the Spc is, the higher is the effect of the information regarding water price changes (Figure 7-18). The illustrated effect is expected, as the experimental variable was designed to portray the “power” that the information regarding water price changes (and not the actual water price change) has towards changing the attitude of the household agents population. It is worth noting that the Athens drought period model included around nine price changes within a period of 12 years, the majority of which were implemented following changes in the country’s economy while few were made as actual water pricing policies. The value of the mean strength of influence of water price changes information for the Athens drought period case is estimated during the calibration phase of the model and integrates the strength of influence of all the water price changes triggered by policy or economy drivers.

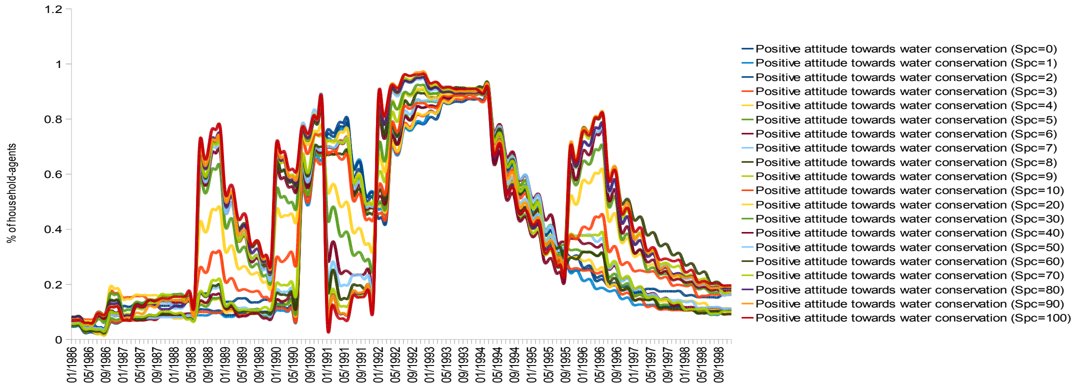


Figure 7-18 Evolution of positive attitude towards water conservation for eleven different values of water prices changes' strength of influence (Spc=0-10, Spc=20 ,Spc=30, Spc=40, Spc=50, Spc=60, Spc=70, Spc=80, Spc=90 and Spc= 100)

7.7.8. Total time of transmitting information regarding water pricing changes (M)

The evolution of positive attitudes is affected by the number of months that the information regarding water price changes is available to the public prior to the actual change of water price. Five values were used for verifying the effect of this parameter to the evolution of positive attitudes towards water conservation. The model behaves as expected (Figure 7-19) by modelling more positive attitudes when the time of transmitting the information regarding water price changes increases.

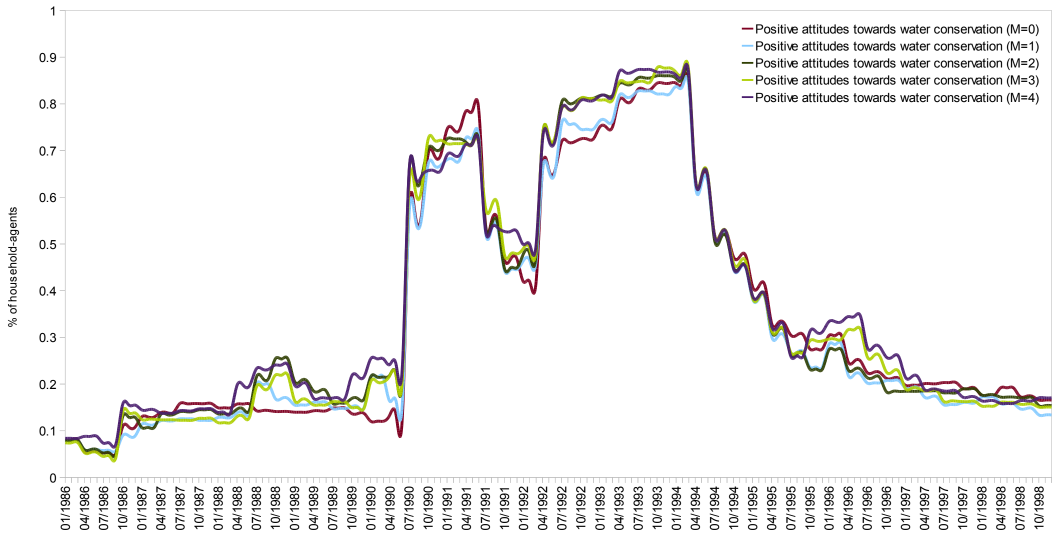


Figure 7-19 Evolution of positive attitude towards water conservation for five different values of total time of transmitting information to the public regarding water prices changes (M=0, M=1, M=2, M=3, M=4))

The above paragraphs presented the results of a model validation process, where its main aim was to identify whether the “translated” concept of UWAB into an actual modelling tool corresponds to what it was designed to be or simply put the above processes answer the question “did we built the thing right?” (Nikolic et al., 2013). Since the conceptualised model is complex, including many agents, their interactions and their different states it was decided to check each experimental variable for consistency with what it was originally designed. The Athens case study was used as a storyline that the UWAB needed to reproduce. That storyline evolved the evolution of the positive attitudes within the Athens household population that is expected to increase during the months with demand management strategies in place. The results of the validation show that the model is actually working, capturing the changes of water conservation attitudes driven by awareness raising campaigns, information regarding a water price change and water restrictions.

7.8. UWAB results

UWAB was set to simulate the behaviour of the population of Athens for 156 months from 1986 to 1998. The results are in the form of number of household agents per water user category and conservation level (Figure 7-20). The effect of both the awareness raising campaigns and the water price changes can be seen in the figure. During 1990, 1992 and 1993 there is an clear behavioural change towards water conservation for all three water user types.

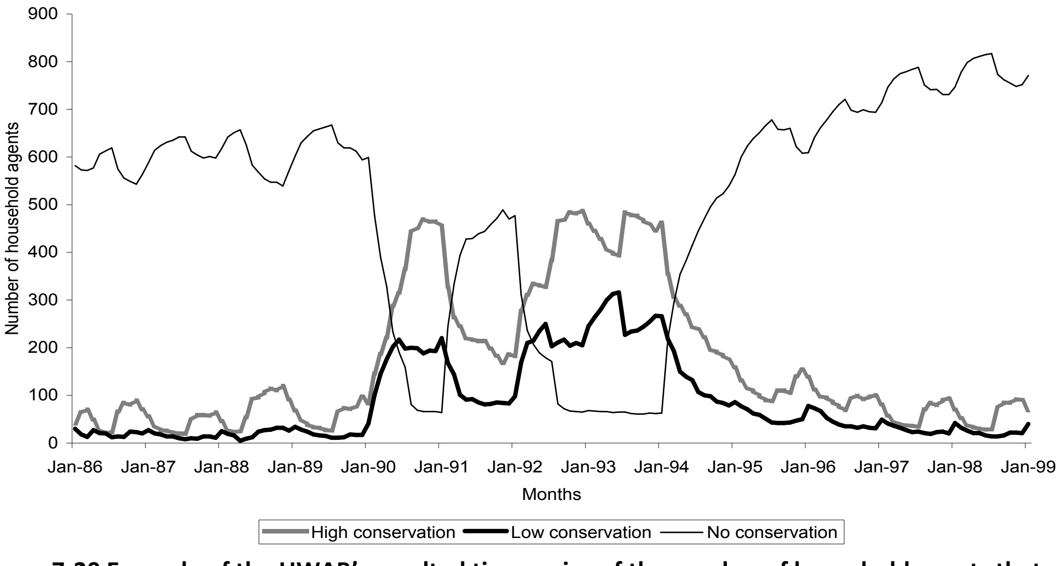


Figure 7-20 Example of the UWAB’s resulted time series of the number of household agents that are average water users and have no, low or high level of water conservation

7.9. Sensitivity and calibration procedure

To examine how good the model performs, results need to be tested in view of their ability to recreate the evolution of domestic water demand from 1986 to 1998. More specifically, the key aspect is whether the model is able to account for the effects of different water demand policies on the household water demand behaviour during the drought period.

7.9.1. UWAB's experimental variables' sensitivity analysis

The final results are computed by combining the results of the UWAB and UWOT. This is achieved by multiplying the number of households for each water user type and water conservation level with their corresponding water demand. The eight experimental variables that are used for the model's sensitivity analysis are (see Annex I and Chapter 4 for details):

- Mean strength of influence for household agents and external influence (S)
- Influence strength of water saving awareness campaigns (S_{AC})
- Influence strength of water price changes information (S_{PC})
- Number of months before and after water price changes that the information is transmitted (M)
- Distribution of positive attitudes towards water conservation (%ipa)
- Distribution of the population affected by an external (to the modelled area) source of positive attitudes towards water conservation (%epa)
- Volatility of social impact (T)
- Social network structure

As discussed in Chapter 4, Latin hypercube sampling was used to sample the multidimensional parameter space and create experiments exploring the sensitivity of the model parameters. One hundred parameter sets were randomly sampled and corresponding experiments were created.

In Matlab, lhsdesign(n,p) generates a Latin hypercube sample containing n values (in this case n = 100), on each of p variables (in this case p = 7). For each column, the 100 values are randomly distributed with one from each interval (0,1/100), (1/100,2/100), ..., (1-1/100,1), and they are randomly permutated. The selected probabilities from the cumulative distribution function are "translated" into values for the experimental variables using the unifinv(P,A,B) function in Matlab that computes the inverse of the uniform cdf with parameters A and B, the minimum and maximum values, respectively, at the corresponding probabilities P, selected through the Latin hypercube sampling process. The above procedure results in the selection of a sample of plausible collections of parameter values from the multidimensional parameter space.

The complex nature of ABMs requires the repetition of experimental runs and the averaging of their results to minimise the effect of an unrepresentative outlier (Nikolic et al., 2013). To identify the number of experimental runs that produce a statistically significant sample it is a necessity to perform a high number of repetitions, reasonably chosen based on the required modelling time, and check the descriptive statistics. If they perform well, it is possible to decrease the experimental runs. For UWAB, 1000 experimental runs were explored that led to the final estimation that 10 experimental runs are adequate. In particular, the overall variability of the outcome was assessed by performing 1000 repetitions of one parameter set and checking the statistics of that outcome. It was calculated that these statistics: mean standard deviation ≈ 1 l/p/d (max st.dev. = 2 l/p/d), skeweness = -0.06 showing a slight longer left tail of the values' probability distribution and kurtosis = 3.08 showing a larger peakedness than the normal distribution. These statistics suggested that there is in fact a very small variation of the model's outcomes and thus 10 repetitions per parameter set up are considered as acceptable to decrease the influence of outliers to the results.

The mean output of the ten repetitions of each of the one hundred sampled parameter sets was used for the sensitivity analysis. The Monte Carlo Analysis Toolbox (Wagener, 2004) was used to visualise the model's sensitivity to the alteration of the experimental global variables and the identification of values or sets of values that are more probable to give results closer to the historical ones. To assess this proximity between modelled and historical values, two objective functions were used, as explained in Chapter 4:

1. The Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970), as modified by Krause et al. (2005) and Herrera et al. (2010) was used for the entire length of the simulation (Equation 7-3). The range of the modified Nash – Sutcliffe coefficient lies between 0 (perfect fit) and +∞. Values of more than one signify that the mean (median) value of the historical time series is a better predictor than the proposed model.

2. The Mean Absolute Percentage Error (MAPE) (Equation 7-4), was used to measure the divergence of the modelled results from the historical values during the intensive water policy response measures period of 1990-1993.

$$NS\,modified\,(pars_k) = \frac{\sum_{i=1}^{156}\left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}}\right)^2}{\sum_{i=1}^{156}\left(\frac{E_{WD_i} - \overline{E}_{WD_i}}{\overline{E}_{WD_i}}\right)^2} \qquad \text{Equation 7-3}$$

$$MAPE\,(pars_k) = \frac{\left|\sum_{January}^{December}\left(\frac{E_{WD_i} - M_{WD_i}(pars_k)}{E_{WD_i}}\right)\right|}{total\ number\ of\ months} \qquad \text{Equation 7-4}$$

where, k denotes the parameter set under investigation (≥ 0)

i denotes the result of the i-th month (1, 156)

j denotes the monthly interval that calculates as well the total number of months (e.g. j = months 12 to 30, total number of months = 18)

M_{WDi} corresponds to the model's results for the i-th month,

E_{WDi} corresponds to the historical water demand for that i-th month

$\overline{E}_{WD_i}$ corresponds to the mean historical water demand for that i-th month and

$pars_k$ corresponds to the respective k-th parameter set, as selected from the Latin hypercube sampling process.

Figure 7-21 presents a Generalised Likelihood Uncertainty Estimation (GLUE) output plot for the modified Nash-Sutcliffe coefficient. This plot displays the model's output with associated confidence intervals with 95% confidence level calculated using the GLUE methodology (Beven and Binley, 1992). For each point in time a cumulative frequency distribution is generated using the selected objective (here the modified Nash-Sutcliffe coefficient) and the confidence intervals calculated using linear interpolation. The bottom graph is added to make regions with large uncertainties easier to identify. It shows the difference between upper and lower confidence limits, normalised by the maximum difference between the two over the investigated period of time (Wagener, 2004).

Figure 7-21 identifies that there is a higher uncertainty associated with model results after 1990 (month 48) when the main domestic water demand strategies were implemented. These are the months were the behaviour of the household agents is actually affected by external to their social network and their intrinsic characteristics forces, such as the water demand management strategies that were in place. A decrease in uncertainty is evident during 1993 (months 85 to 96), but this may easily be attributed to the fact that the restrictions that were implemented during 1993 are only represented in UWAB as a household agent parameter without changing UWOT's frequencies of water use. The result of the above modelling decision was that the model has a greater divergence with the historical data during the months of 1993 and therefore a lower uncertainty.

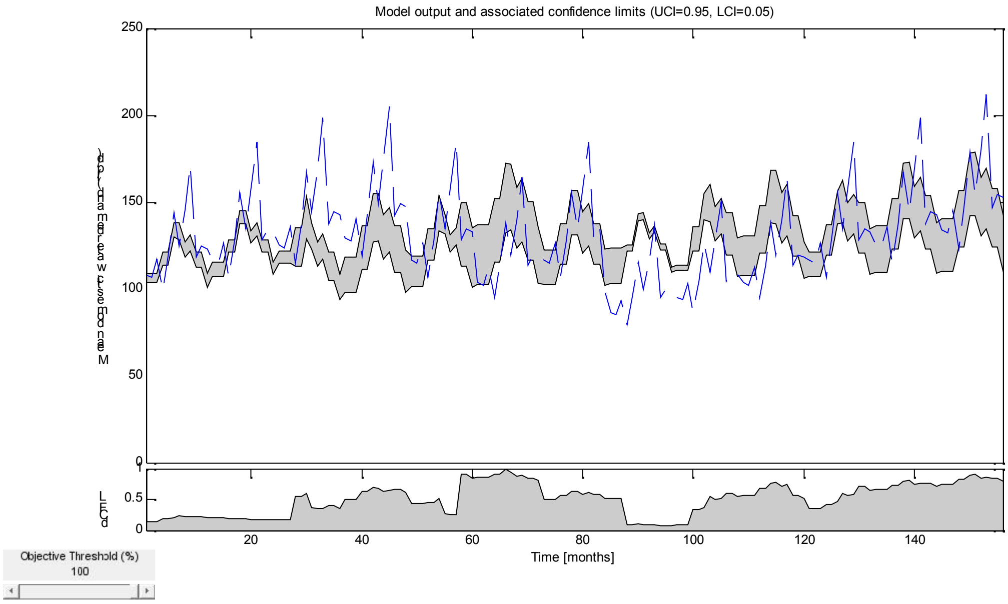


Figure 7-21 GLUE output uncertainty plot (automatically generated using the MCAT) (blue line = observed values, grey area = confidence limits, dCFL = normalised difference between upper and lower confidence limits)

Figure 7-22 and Figure 7-23 present identifiability plots, created using the Monte Carlo Analysis Toolbox (Wagener, 2004). Figure 7-22 uses the modified Nash-Sutcliffe coefficient while Figure 7-23 uses the mean absolute percentage errors. The plots represent parameter identifiability using the gradient of the cumulative likelihood distribution. The identifiability plots are created by selecting the best performing 10% of each parameter population and calculating the cumulative distribution of the parameter using only this best performing set. The parameter ranges are then split into 10 bins and the gradient is calculated for each bin. A high gradient shows that the parameter is most identifiable at that specific range. Thus, the most identifiable parameters - those which affect the output and can be estimated with some degree of certainty - are those that exhibit high and dark bars and steep slope (Wagener, 2004).

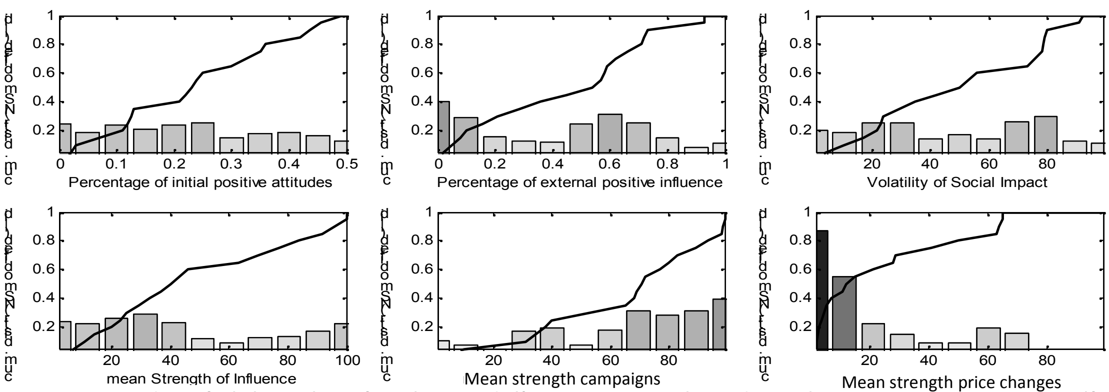


Figure 7-22 Identifiability plots for the model's parameters based on the modified Nash-Sutcliffe coefficient

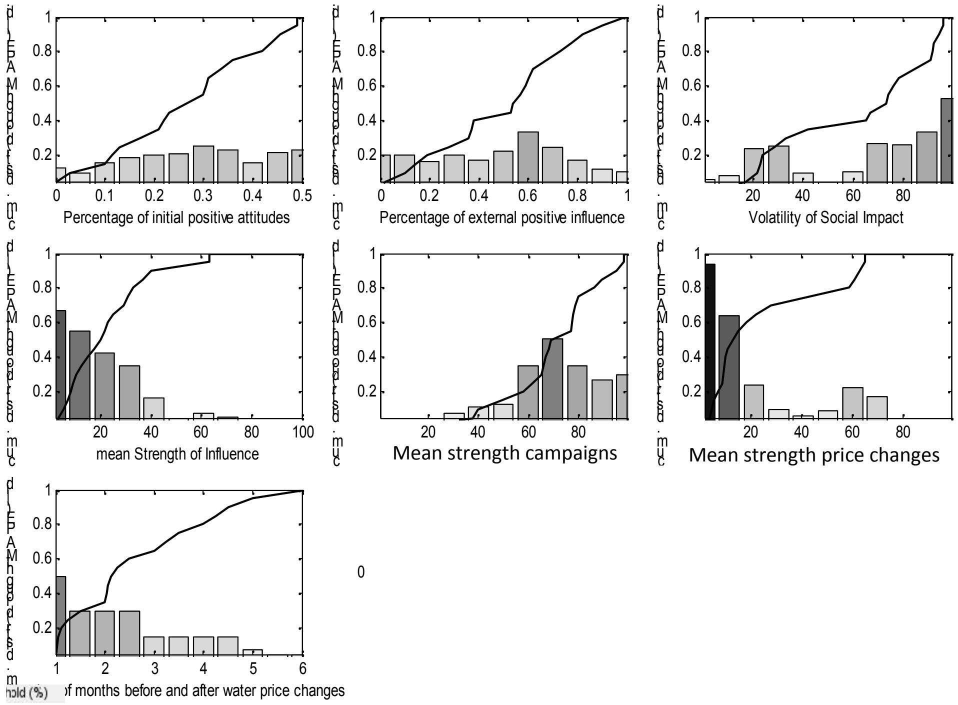


Figure 7-23 Identifiability plots for the model's parameters based on the mean absolute percentage error

The analysis of Figure 7-22 and Figure 7-23 led to the identification of the value ranges within which the parameters are most identifiable (Table 7-10). These value ranges are used in the model's optimisation procedure as constraints.

Table 7-10 Most identifiable value ranges for the experimental variables

Experimental Variable	Selected constraint
External positive influence (epa%) (x 100%)	0.6 - 0.8
Initial positive attitude (ipa%) (x 100%)	0.3 - 0.4
Volatility of Social Impact (T)	10 – 40
Mean strength of influence (S)	0 – 30
Mean strength of influence regarding awareness raising campaigns (S_{AC})	60 – 80
Mean strength of influence regarding water price changes (S_{PC})	0 – 20
Number of months before and after a water price change that the information is transmitted (M)	0 – 3

The complex network structure was not possible to be assessed using identifiability plots since the two possible structures could be described only by using binary variables of on (=1) or off (=0) values. Nevertheless, both social network structures produced acceptable results with the small-world network structure performing better in the mean absolute percentage error. However the ability of the scale-free network to be built dynamically, by incorporating a preferential attachment strategy (Nikolic and Kasmire, 2012) makes this structure preferable. This dynamic build up allows the incorporation of new households, added in our case every year, representing population increase. These new households are connected to those existing households that already are connected with more agent households that their peers so as to follow the preferential attachment's "the rich getting richer" rule.

7.9.2. UWAB's experimental variables calibration

The sensitivity analysis led to the selection of value ranges for the experimental variables that were then subject to the multi-objective calibration process (Table 7-10). The experimental variables were calibrated using a multi-objective genetic algorithm (Deb, 2001) aiming to minimise the two objective functions used in the sensitivity analysis: the Nash-Sutcliffe modified coefficient and the 1990-1993 mean absolute percentage error. A function was created to allow the genetic algorithm to run UWAB for each parameter set, combine its results with those of UWOT and estimate the value of the selected objective functions[6].

Table 7-11 summarises the parameter sets that resulted from the multi-objective genetic algorithm run for 10, 30, 70 and 100 iterations (when the algorithm reached its stopping criteria). Each iteration includes ten different parameter sets and therefore UWAB run for 100, 300, 700 and 1000 times respectively. The 100 iterations (1000 UWAB runs) require approximately 36 hours of simulation. Due to the high simulation time of the model's calibration process it was decided to run each parameter set once but repeat the whole calibration process 5 times in order to decrease any possibility of the results being outliers. The results of the repetitions are the parameter sets for the 100 iterations' process reported in Table 7-11. Figure 7-24 presents the resulting Pareto fronts for different numbers of iterations. The results of these parameter sets are presented and discussed in the following paragraph.

Table 7-11 Parameter sets resulted from the genetic algorithm calibration process.

	ipa%	epa%	T	S	S_{AC}	S_{PC}	M
1000 model outputs (100 iterations)	0.255	0.685	10.416	2.925	71.370	0.815	2.359
	0.262	0.669	10.528	2.566	70.056	0.778	2.457
	0.246	0.684	10.441	3.363	70.248	0.880	2.290
	0.246	0.685	10.441	3.363	70.249	0.880	2.290
700 model outputs (70 iterations)	0.274	0.610	10.669	2.199	69.650	0.574	2.469
	0.239	0.702	10.380	3.683	71.783	0.903	2.111
	0.253	0.690	10.395	3.457	71.834	0.874	2.269
	0.274	0.610	10.669	2.199	69.650	0.574	2.469
	0.256	0.682	10.439	2.715	70.951	0.814	2.373
	0.239	0.702	10.380	3.683	71.783	0.903	2.111
300 model outputs (30 iterations)	0.270	0.670	10.357	2.654	72.767	0.869	2.291
	0.274	0.610	10.669	2.199	69.650	0.574	2.469
	0.270	0.681	10.502	3.121	70.695	0.645	2.417
	0.239	0.703	10.380	3.683	71.783	0.903	2.111
	0.264	0.689	10.478	3.236	70.876	0.719	2.344
	0.260	0.692	10.406	3.674	70.990	0.754	2.277
	0.252	0.660	10.412	2.523	70.815	0.805	2.239
100 model outputs (10 iterations)	0.270	0.670	10.357	2.654	72.767	0.869	2.291
	0.274	0.610	10.669	2.199	69.650	0.574	2.469
	0.270	0.670	10.357	3.647	71.767	0.869	2.080

[6] The function, the code used for calling NetLogo using Matlab or Octave and the Java code used for running the UWAB headless can be found in Annex VI.

Mean values	0.259	0.669	10.467	2.987	70.967	0.779	2.309
Standard deviation	0.013	0.032	0.113	0.568	0.998	0.124	0.130

* ipa%: percentage of initial positive attitudes, epa%: percentage of external positive influence, T: volatility of social impact, S: mean strength of influence, S_{AC}: mean strength of influence for awareness campaigns, S_{PC}: mean strength of influence for water price changes, M: number of months before and after a water price change that the information is transmitted.

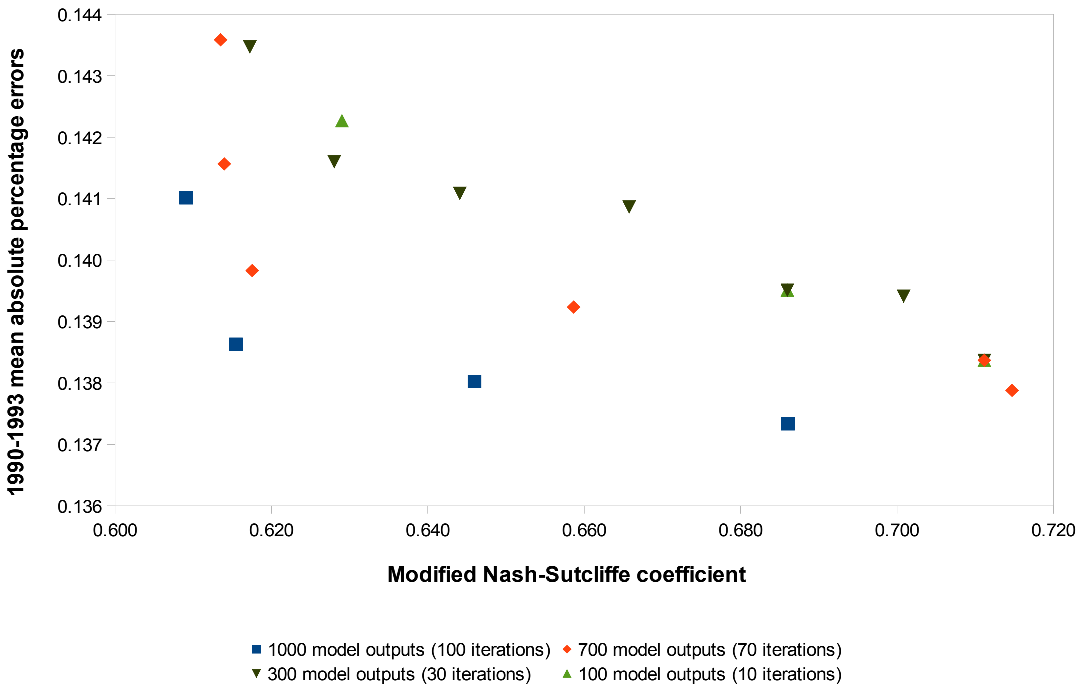


Figure 7-24 Pareto fronts resulted from the multi-objective algorithm minimising both selected objective functions. Objective functions' results are given for different iteration numbers.

7.10. Results and discussion

The modelling platform was initialised based on the results of the optimisation process for 1000 model outputs (100 iterations) and run 100 times each optimisation solution.

Figure 7-25 presents the results for the 1988-1994 drought period. The mean modified Nash-Sutcliff coefficient is 0.64 showing that the created model is a better predictor than the mean of the observed data and the mean MAPE (Mean Absolute Percentage Error) for 1990-1993 period is 0.14, which means a 14% error within the estimated water demand.

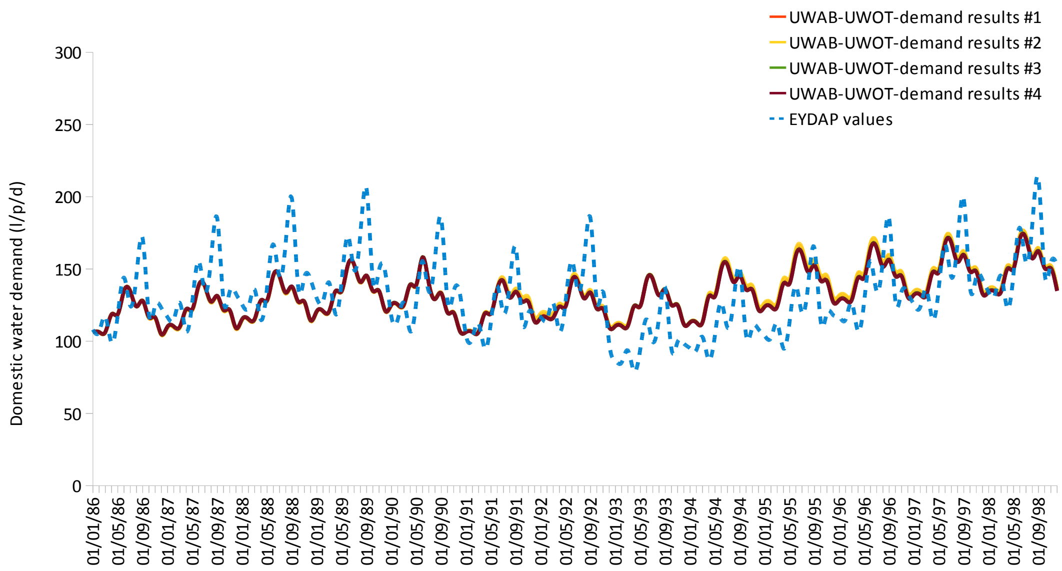


Figure 7-25 Results of simulated Athens 1988-1994 drought period

The results reveal a number of interesting insights regarding the system's behaviour during the drought:

- The comparison between the frequencies of use for the different water user types with those, reported by the respondents of the 2013 online survey, show a big discrepancy in the values. The 2013 frequencies of use are by 70% higher than the frequencies of use that were estimated in order to result in specific water demand volumes for the different water user types (see Chapter 7). The differences may be attributed to three issues:

    i. Year difference: the online survey was held in 2013 and the estimated frequencies of use are for 1986. The comparison of the estimated frequencies of use for 1998 with those reported in the online survey result in a noticeably smaller difference of 60%.

    ii. Mean values difference: the estimated frequencies of use were selected so as to result in a predefined water demand per water user type. It is assumed that these frequencies of use are mean values and integrate the use of appliances for households that are empty most of the day (employed young people) and mostly full (retired or families with small children). As such they represent idealised mean cases that do not correspond well with actual replies – although they perform well for simulation purposes.

    iii. Difference in appliances technologies: if the values reported in the online survey were used as a UWOT input, it would correspond to an average water demand of 550 litres per person per day. This is clearly an excessive, unrealistic figure. This result may be attributed to both mean values difference (see issue b above) and to the difference of water appliances between 1986 and 2013.

- The increased 1993 reduction of water demand can be mainly attributed to the addition of water use restrictions in the policy mix. Water use restrictions that were imposed in 1993 were included within the behavioural intention rule of high and low conservation increasing the probability that a household agent would decide to conserve water. To avoid a case specific "correction" of the UWOT in-house appliances' frequency of use of that year it was decided not to include the effect of water restrictions to the UWOT model, by eliminating the frequency of use for the outside water uses during that particular year. Such an intervention to the UWOT frequency of use time series would have been misleading in capturing the behavioural change of the Athenian household, since the household agent would still need to decide whether or not to obey to the restriction and thus change the frequency of the outdoor uses to zero. Therefore, the inclusion of the water restrictions to the UWOT time series would have required an extra behavioural rule, with at least one more experimental variable, that would have created another characterisation of the household agent, that of "implementing water restrictions" doubling the number of time series resulting from the two models (3 water user types x 3 conservation levels x 5 occupancy levels x 2 restrictions behaviour = 90 time series). This approach however would be easier to implement with a dynamic coupling of the two models, something that it is considered a next step of this research (see Chapter 9). However, it was decided not to integrate the restrictions in the UWOT model and assess the effect of this "anomaly" on the simulation results. Having that in mind, the mean absolute percentage error for 1990-1992 is around 10%, while the mean absolute percentage error for 1993 more than doubles at about 25% (Figure 7-26). Using the knowledge obtained about the increase of error when the water restrictions are not included within the UWOT's frequency of use time series, in the scenarios presented in Chapter 8, restrictions are in fact included in the frequencies of use for the high water conservation level restricting outdoor water uses and their effects are taken into account in the scenario results.

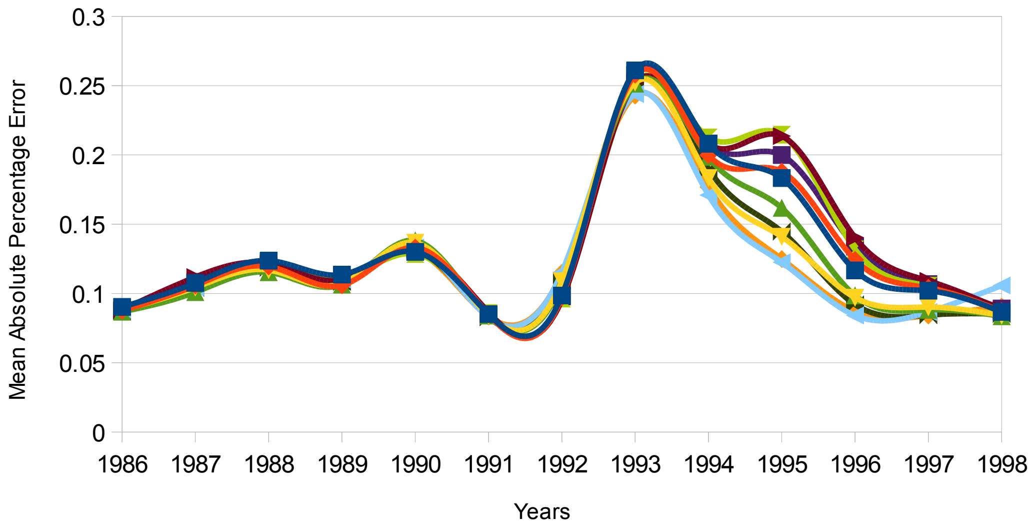


Figure 7-26 Mean absolute percentage error per year.

- The application to the Athens drought period presented a mean error of 10% (excluding the misleading effect due to restrictions discussed above). As seen in Figure 7-28 the main differences were in the peaks of water demand. These inconsistencies may attributed to the method of including the seasonal variation of water demand, altering the frequency of use for three appliances based on the study of Rozos and Makropoulos (2013). In future real world applications, an end user study could give more insight regarding the seasonal use of water appliances. Despite this discrepancy the results were able to capture the direction (decrease and increase) of domestic water demand. Figure 7-27 presents the mean monthly water demand resulting from the UWAB-UWOT modelling platform in comparison with the mean monthly demand as provided by the relevant EYDAP S.A. report (EYDAP, 2009).

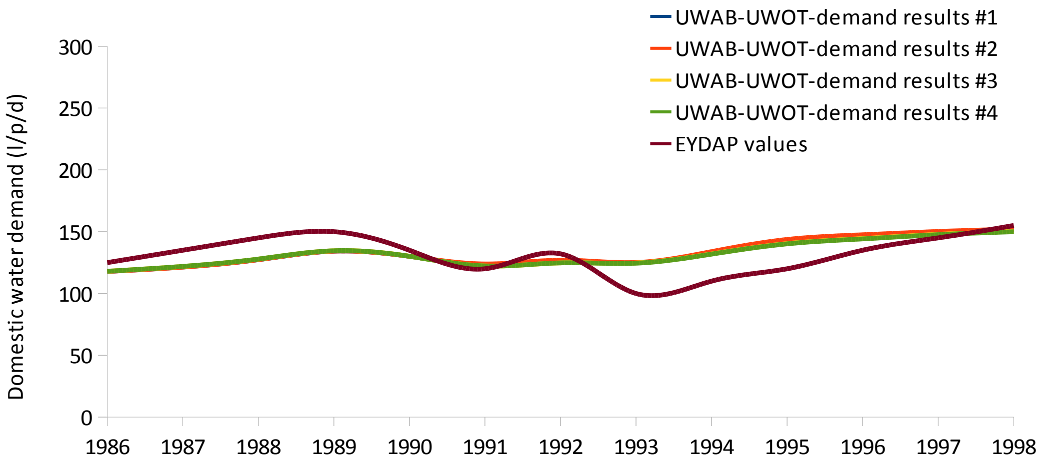


Figure 7-27 Simulated versus historical values of mean monthly domestic water demand

- The historical data are best fitted with a much lower strength of influence for water price changes than the strength of influence for awareness campaigns. As explained before the model only accounts for the effect of the information that water price has changed and disregards actual price differentials. As such, the simplification is that all eight water price changes during the period in question had the same strength of influence to the population of Athens. This is clearly not the case and some differentiation related to the magnitude of change is also warranted. Further research could incorporate for example an econometric rule that would simulate the effect of the actual water price change in the water demand behaviour.

- The historical data are best fitted with low values of volatility of social impact ($T \approx 10$). This result indicates that the society under investigation is rather susceptible to effects of social norms, meaning that people are more influenced by their social network rather than the external forces exerted to them.

7.11. Conclusions

UWAB's parameters related to the social, living and economic conditions of the Athens drought period of 1988-1994 were set based on available data including age, education, housing conditions, household's occupancy and income level distributions within the population of Athens. However, several parameters required by UWAB could not be defined based on available historical data. These parameters include: (a). the social network's structure, (b) the distribution of positive attitudes towards water conservation, (c) the distribution of the population affected by an external (to the modelled area) source of positive attitudes towards water conservation, (d) the Volatility of Social Impact, (e) the mean strength of influence (S), (f) the influence strength of water saving awareness campaigns (S_{AC}), (g) the influence strength of water price changes information (S_{PC}) and finally (h) the total time of transmitting information regarding water pricing changes (M). . These were assigned values based on a calibration process.

EYDAP S.A. provided data regarding the pricing policies and awareness raising campaigns between 1988-1994. Time series were available regarding the total mean monthly domestic water demand and the seasonal and annual trends of domestic water demand. The schematisation of the Athens hydrosystem was also known. However, several UWOT parameters were based on assumptions mainly concerning the domestic water demand of different categories of water users and the frequencies of use of in-house appliances for three conservation types (non, low and high). The parameterisation of UWOT was also informed by the results of the surveys that were held in 2013.

During 1993 central authorities increased their efforts for further reducing domestic water demand. On top of the awareness campaigns and the increase of water prices that were already in force, they also imposed water use restrictions to outside uses and penalties to heavy water users (Kanakoudis, 2008). These extra water policies resulted in a 52% reduction of mean monthly water demand, compared with the expected one (Kanakoudis, 2008). In our modelling work, these extra water policies do not alter the frequencies of use, and are taken into account through a dummy variable in the decision function of the household agents increasing the probability of water conservation behaviour when restrictions are in place.

After setting up the two models, a calibration procedure was undertaken to identify the appropriate values for the experimental global variables of UWAB. The calibration algorithm resulted in a Pareto set of experimental global variable value sets which were used to simulate the Athens 1988-1994 drought period. The model ran 10 times for each value set and the results were averaged before being integrated with UWOT's results.

The implementation of UWAB to Athens' 1988-1994 drought period was used to validate the UWAB model's design features. Results suggest that despite limitations the model does reproduce adequately the observed behaviour of the complex system of Athens. That is not to say that the model does not contain several simplified assumptions and artefacts (Galan et al., 2009). Nevertheless, the model’s results show that the household agent population reacts in a “common sense” way, meaning it reconsiders its water conservation behaviour when signals are sent regarding water prices changes and awareness campaigns and forgets about water saving, returning to its common use, when policies are not in place. This “looking right” model results can be taken as a sign of model verification (Crooks et al., 2008). This would have certainly not been enough for a physically based model (such as hydraulic simulation models) where field observations together with a clear articulation of physical laws can take the validation procedure to much more detailed levels. However social simulation of the kind that is needed to look into water demand management effects unfortunately does not afford such levels of certainty (Nikolic et al., 2013).

The following Chapter 8 presents the application of the platform in assessing the effects of alternative water demand management strategies for the Athens urban water system.

Chapter 8. Applying the modelling framework for assessing water demand management strategies: the case study of the Athens urban water system

8.1. Introduction

This chapter presents the implementation of the UWAB-UWOT modelling platform in a series of scenarios for different water demand and supply levels and assesses the effect of different water demand management strategies on the urban water system of Athens.

Seven water demand management strategies, five water demand scenarios and ten water supply time series of ten years of net inflow to the Athens urban water system are developed and examined for the purposes of this work. Firstly, each one of the ten water supply time series were used to assess the impact of the different water demand scenarios without implementing any water demand management policies. This was done to identify the behaviour of the urban water system against different water demand volumes under a “do nothing” baseline. This procedure identified those water supply time series and water demand scenarios that cause the Athens urban water system to fail by not being able to meet the requested water demand. Then, experiments of water demand management strategies were created to assess the effect of different demand management strategies to the system and to decrease or avoid unmet water demand.

The purpose of this exercise is to demonstrate the ability of the platform to support decisions makers in planning water demand management strategies. It does not aim to propose measures for the Athens urban water system, although the results of the scenarios provide a “glance” into what-if scenarios regarding the evolution of the system’s performance.

8.1.1. Water demand management strategies

Seven water demand management strategies were designed following the basic notions of the demand management strategy that was applied during the Athens drought period of 1988-1994. The designed water demand management strategies are built trying to answer "what-if" questions, adding extra measures serially and assessing the effect of these supplementary measures to the domestic water demand behaviour. These are:

Baseline: No policies are in place

Strategy a: Awareness raising campaigns when water availability is low

Strategy b: Awareness raising campaigns when water availability is low and/or every two years for 6 months

Strategy c: Awareness raising campaigns when water availability is low and/or every two years for 12 months

Strategy d: Awareness raising campaigns and restrictions when water availability is low and/or awareness raising campaigns every two years for 12 months

Strategy e: Awareness raising campaigns when water availability is low and/or every two years for 12 months plus water price increase when water availability is low for more than 12 months

Strategy f: Awareness raising campaigns and restrictions when water availability is low and/or awareness raising campaigns every two years for 12 months plus water price increase when water availability is low for more than 12 months

These strategies were implemented in different water demand and supply scenarios. UWAB was used to create experiments simulating the effect of the different water demand management strategies to the agents' water demand behaviour. The methodology presented in Chapter 4 and the tools presented in Chapter 5 were used to setup these experiments. Each experiment was repeated ten times and the average results were used for assessing the effect of the different strategies to the Athens urban water system using the UWOT model.

8.1.2. Water demand scenarios

The UWAB model which was calibrated using the Athens drought period of 1988-1994 in Chapter 7 was updated to account for socio-demographic differences reported in the most recent Greek National Statistical Office's data (the 2011 Census). These included the household population, the distribution of the household members, age levels, housing conditions and education levels (see Chapter 5 for details regarding the evolution of the Athens' population). In terms of the income level, it was decided to be left at the same levels as those of the 1990s, representing the economic crisis that the country is undergoing for the past 5 years (OECD, 2013). Furthermore, based on the results of the online survey 30% of the population has a positive attitude towards water conservation which is not far from the calibrated parameter value of the UWAB-UWOT model of 26%. Therefore, since 26% refers to the 90s and was calibrated so as to fit the evolution of water demand during the

Athens drought period of 1988-1994 it was decided that for the scenarios, the initial positive attitudes was to be set at the same value as the results from the online survey.

Five water demand scenarios were built: a baseline scenario, an increased water demand behaviour scenario and three population increase scenarios.

The baseline scenario is based on the water demand of 2009, while the increased water demand behaviour scenario is based on an increase of the frequencies of use due to an (assumed post crisis) quality of life increase. The Athenian population has been projected to either remain unchanged or slightly decrease in the next decade, due to both an aging population and a persisting economic crisis (Kalogirou et al., 2011). However, the total water withdrawal from EYDAP's water treatment plants could increase, if EYDAP S.A. decides to directly provide water to more municipalities (e.g. Korinthos). The population increase scenarios assess cases of 7%, 12% and 22% increase of the population served by EYDAP S.A. that correspond to an increase in water demand of around 30%, 45% and 50% respectively compared to current water withdrawals.

The volumes of the water demand scenarios were also examined in a recent raw water cost study (Makropoulos et al., 2011). In that study, which was formally adopted by both ministry of Public Works and EYDAP SA the 95% reliability factor was considered as the lowest acceptable level for the safe operation of the Athens hydrosystem.

The water demand scenarios are as follows:

Scenario 1: Baseline (370 hm^3): Athens domestic water demand of 2009 (EYDAP communication, 2014)

Scenario 2: Increased water demand (450 hm^3): used in the study by Makropoulos et al., (2011) resulting in a 97% reliability factor for the Athens hydrosystem

Scenario 3: Increased population by 7% (480 hm^3): used in the study by Makropoulos et al., (2011) resulting in a 95% reliability factor for the Athens hydrosystem

Scenario 4: Increased population by 12% (500 hm^3): used in the study by Makropoulos et al., (2011) resulting in a 97% reliability factor for a hypothetical upgrade of the Athens hydrosystem

Scenario 5: Increased population by 20% (550 hm^3): used in the study by Makropoulos et al., (2011) resulting in a 95% reliability factor for a hypothetical upgrade of the Athens hydrosystem

Based on EYDAP data (EYDAP, 2009), the abstracted water from the four water treatment plants is used as follows: 50% for domestic use, 28% is lost from the distribution system and the remaining 22% is used from municipal, industrial and commercial activities (Figure 8-1).

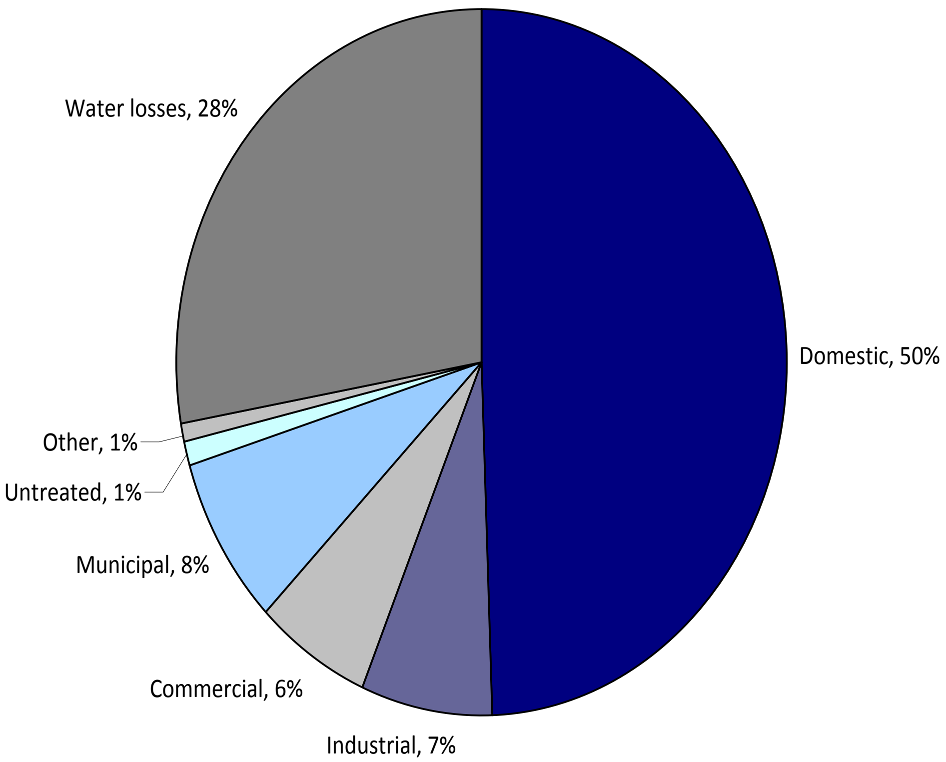


Figure 8-1 Distribution of water uses of the water leaving Athens' four treatment plants with average percentage of use from 1973-2008 (EYDAP, 2009)

Figure 8-2 presents the monthly distribution of water demand to the four water treatment plants, following their historical distribution but for the scenario volumes. These four time series were used as input to the UWOT model of the Athens urban water system.

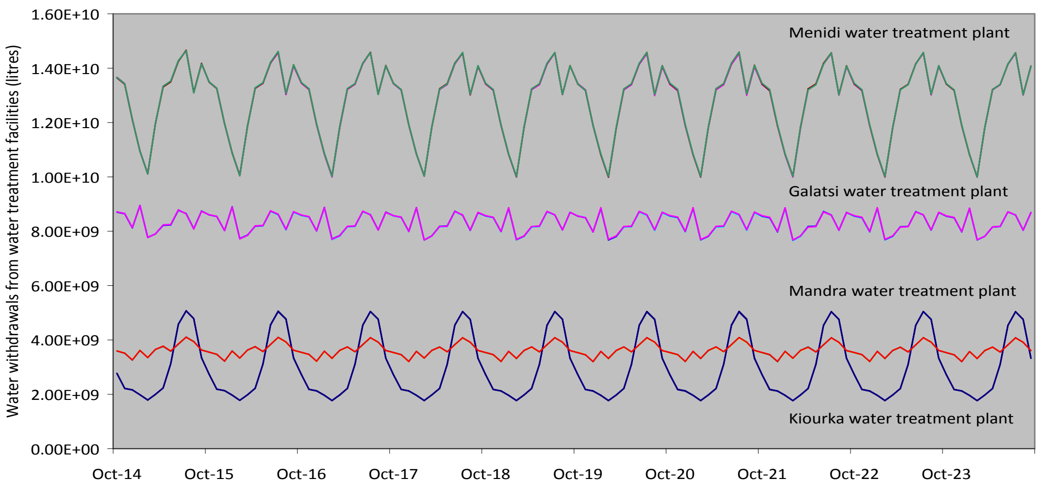


Figure 8-2 Monthly distribution of water withdrawals to the four water treatment plants that supply water to the Athenian households.

The amount of water demand per household water user level was estimated using the procedure presented in Chapter 4 and applied in Chapter 7 for the Athens drought period.

8.1.3. Water supply time series

The UWOT model of the Athens hydrosystem used for this part of the work was taken from Baki and Makropoulos (2014). This model was calibrated to recreate the results of the Hydronomeas model, which is used by EYDAP to analyse the Athens hydrosystem, for a 99% reliability level. The UWOT model of Athens external hydrosystem uses as input time series the net water inflow to the four water reservoirs that supply water to Athens (Hylike, Marathons, Mornos and Evinos). Figure 8-3 presents the average and long term annual average of 100 years of net inflow to the Athens water supply reservoirs.

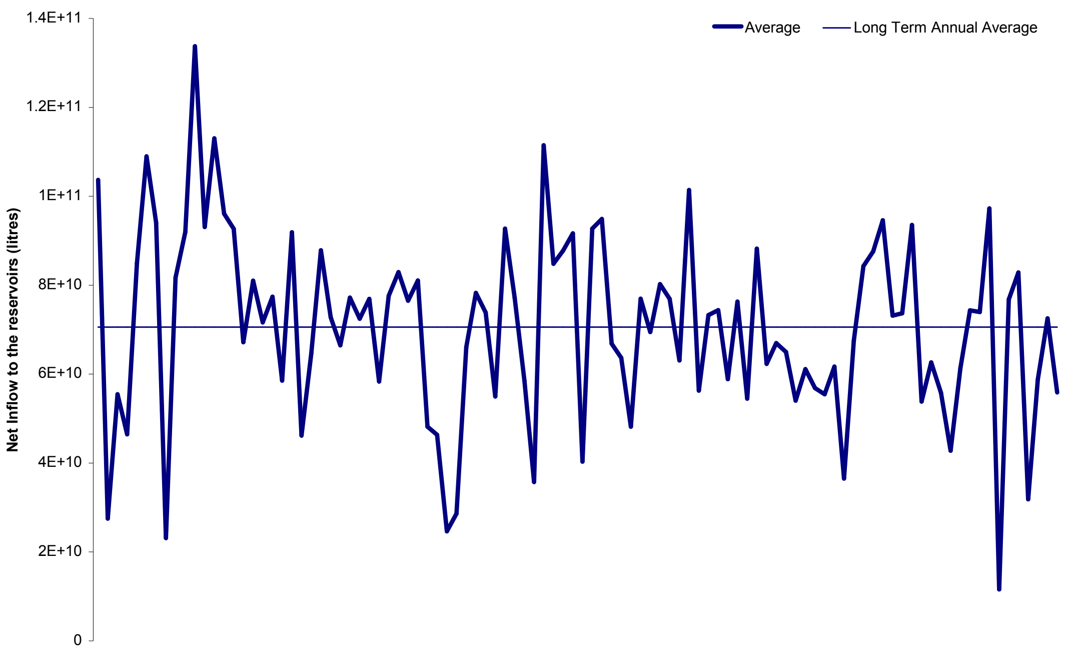


Figure 8-3 Average and long term annual average of net inflow to Athens' water supply reservoirs.

The 100 years monthly time series were divided into decades and ten different time series of net inflow were created for each one of the reservoirs. The initial water storage of the reservoirs was set to that of the 30th of September 2014. The synthetic time series were created using the Castalia software (Castalia, 2008) and historical time series of precipitation and evapotranspiration for the four river basins that provide inflow to the corresponding reservoirs found in www.itia.ntua.gr/eydap/db/ (also used in Baki and Makropoulos, 2014). The simulation ran, with a monthly time step, from October 2014 to September 2024.

The experiments of water demand management strategies are built taking into account an external (natural) pressure: water availability. Water availability is important for UWAB model since it is one of the factors affecting domestic water demand behaviour of the agents. In the case of the Athens drought this factor was set based on historical information available, regarding the onset and the end of the drought period. For the purposes of the scenarios, a low water supply index was estimated by comparing the average net inflow with the long term annual average net inflow. The low water supply index was set to zero, signifying a “normal” year, if the average annual net inflow was more than 60% that of the long term annual average. The low water supply index was set to one, indicating a year of reduced net inflow to the reservoirs, if the average annual net inflow was less than 60% that of the long term annual average (Figure 8-4).

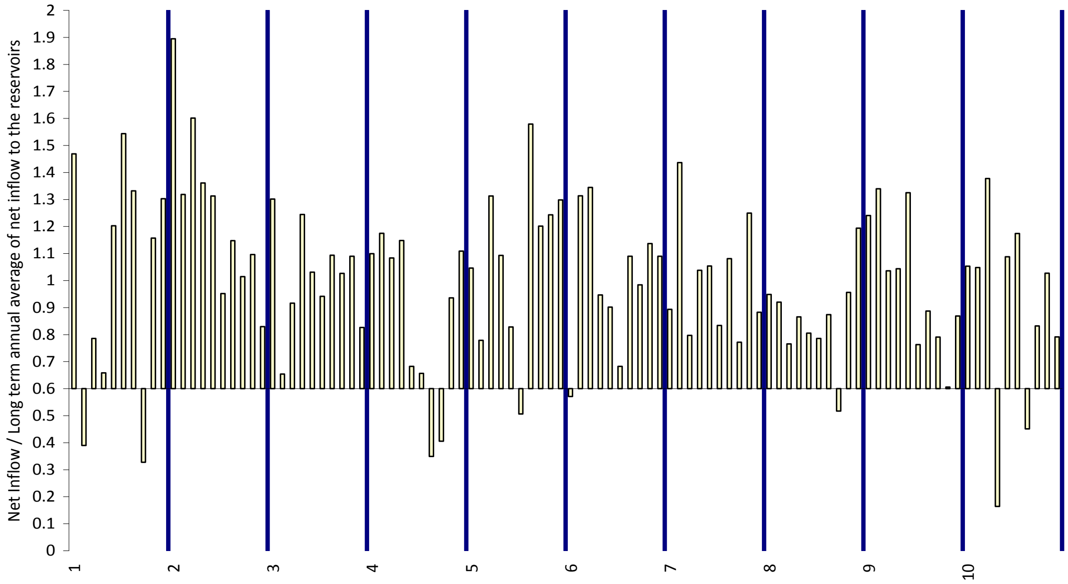


Figure 8-4 Comparing average with long term annual average values of net inflow for the ten synthetic decades.

Figure 8-5 shows that when the model runs with the synthetic net inflow time series and the real water demand of 2009 (370 hm^3 see Chapter 6 for more information regarding time series of water demand) the hydrosystem presents a fall in available water storage for decades number 1, 4 and 10. Therefore, the threshold of 60% is considered adequate to indicate low water supply and appears to be able to adequately identify problematic situations since it does identify those three decades (and two more). Additionally, these three decades, numbered 1, 4 and 10, present two years with a low available water storage and these were selected as the “worst case” scenarios and were used in the water demand scenarios.

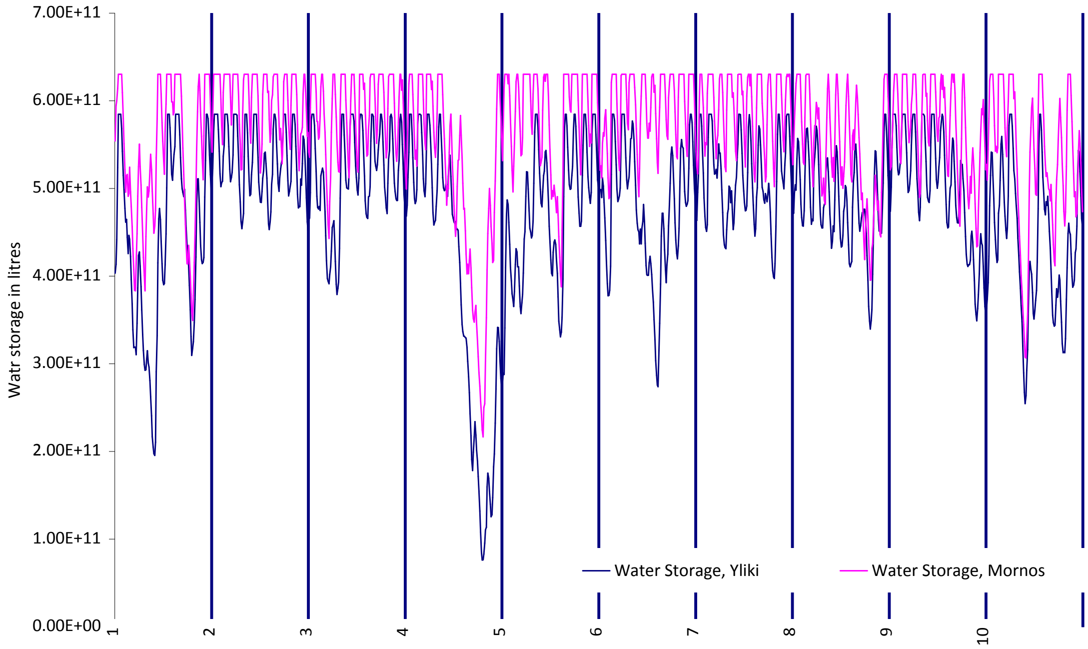


Figure 8-5 Water storage in litres for Hylike and Mornos estimated using UWOT for current water demand of 370 hm^3.

8.2. Assessment of water demand scenarios

The following paragraphs present the effect of each water demand scenario to the Athens' hydrosystem for the three water supply scenarios that were identified as "worst cases" (1st, 4th and 10th time series) without implementing any water demand management strategy.

8.2.1. Scenario 1: Baseline (370 hm^3)

This scenario presents the behaviour of the Athens hydrosystem to the water supply scenarios and the existing conditions of population and domestic water demand. The in-house water appliances which were used to set up UWOT for the average Athenian household of 2013 were selected based on a) the results of the 2013 online survey and b) relevant scientific and policy literature (see below). It was assumed that the types of appliances have not changed from those used in estimating water demand for the Athens drought period case study (Chapter 7). However, the water consumption of some of these appliances, the kitchen sink, the hand basin and the washing machine, has been updated to more recent technologies with lower consumption. These in-house water appliances and their corresponding water consumption are:

- Conventional kitchen sink (KS) (consuming 2.1 litres per use based on EA, 2007)

- Conventional hand basin (HB) (consuming 2.1 litres per use based on EA, 2007)

- Conventional dish washer (DW) (consuming 35 litres per use based on EEA, 2001)

- Conventional toilet (T) (consuming 9 litres per use based on EEA, 2001)
- Conventional washing machine (WM) (consuming 60 litres per use based on EA, 2007)
- Conventional shower head (SH) (consuming 60 litres per use based on Grant, 2006)
- Conventional 30 meter hose for outdoor uses (GA) (consuming 10 litres per use based on Grant, 2006)

Table 8-1 presents the mean frequencies of use for each appliance that was estimated to allow UWOT to simulate the water demand of Athenian households that adds up to a total water withdrawal from the water treatment plants of 370 hm^3. The frequency of use of the appliances is higher than that of the Athens drought period case study mainly because of the increase of living standards and the decrease of water use of several appliances (kitchen sink, wash basin and washing machine).

The comparison between the frequencies of use for the different water user types with those reported by the respondents of the 2013 online survey shows a discrepancy in the values. However, this discrepancy is lower (50%) than that reported for the case study of the Athens drought period (which was close to 70% - see Chapter 7). These (significant) differences may be attributed to the fact that the estimated frequencies of use were reverse engineered to result in a predetermined water demand per water user type (which is itself a scenario rather than current reality). It should also be noted that these average frequencies are in fact compensating for households that are empty most of the day (employed young people) as well as houses that are mostly full (retired or families with small children). As such there should not be expected to match well with actual reported frequencies of specific households.

It is highlighted that there is more than one combination of mean frequencies of use for the selected appliances that will result in the required water demand and as such the frequencies reported in this work should not be treated as findings of the study but rather as simply scenarios whose purpose is to parameterise UWOT.

Table 8-1 Mean Frequency of Use (times per day) for Scenario 1

	Mean Frequency of Use (times per day)								
	Average user			Low user			High user		
	Conservation level:			Conservation level:			Conservation level:		
Appliance	No	Low	High	No	Low	High	No	Low	High
Kitchen sink	3.17	2.76	2.35	1.99	1.73	1.47	3.18	2.76	2.35
Hand basin	5.29	4.81	3.7	4.95	4.51	3.47	5.30	4.82	3.71
Dish washer	0.05	0.05	0.05	0.15	0.15	0.15	0.21	0.2	0.2
Toilet	7.38	5.98	4.94	4.95	4.01	3.32	7.41	6	4.97
Washing machine	0.15	0.14	0.13	0.15	0.15	0.14	0.26	0.25	0.24
Shower	0.55	0.54	0.45	0.46	0.45	0.37	0.75	0.75	0.62
Outdoor uses	0.46	0.35	0.1	0.26	0.2	0.06	0.49	0.38	0.11
Mean monthly water demand (l/p/d)	157	138	113	126	113	93	188	169	140

The water demand was used to produce water bills for the household agents using the tariffs of December 2013 (CMD, 2013). UWAB ran without any water demand management strategy in place and household agents' water conservation attitude was influenced by their social network (in and out of the area under investigation) and by drought conditions and with the values of the experimental variables set by the calibration undertaken in the Athens drought case study. The model results were estimated by the mean value of ten consecutive UWAB simulations to decrease the effects of outliers. It was decided to allow the UWAB model to run for extra 12 time steps (months) in the beginning of the simulation to allow the agents to recalibrate their attitudes and behaviours based on the social impact of their network. Therefore the UWAB's results were used from time step 13 to 132.

Figure 8-6 and Figure 8-7 present the reaction to the water demand scenario 1 of the two main water supply reservoirs, Hylike and Mornos for the three water supply time series (number 1, 4 and 10) that demonstrated a low water availability. The reaction of the hydrosystem is satisfactory without any failures present.

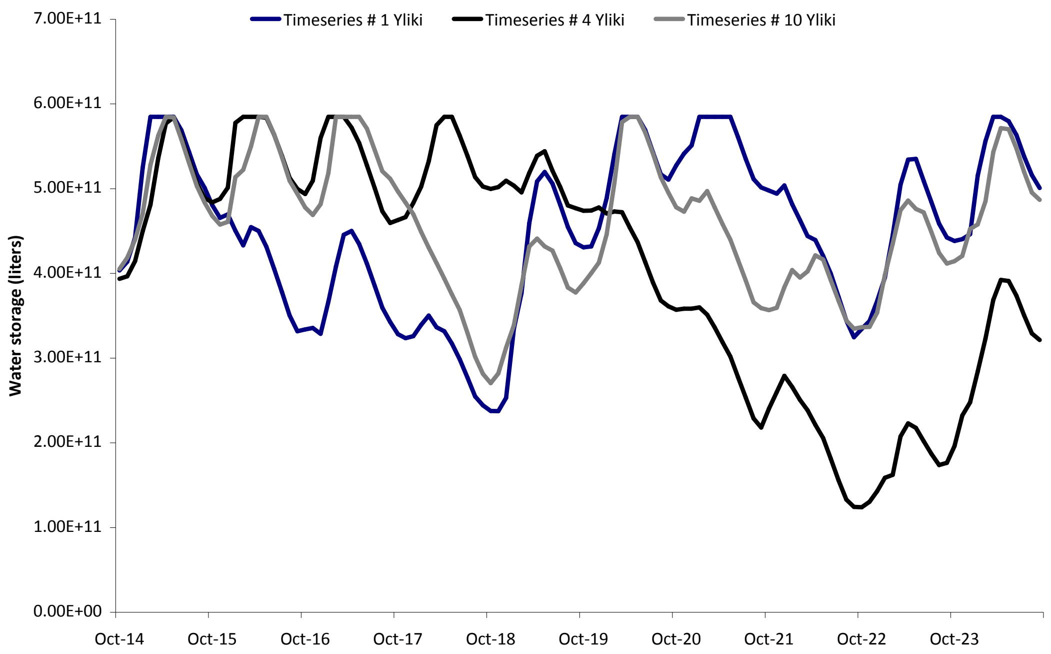


Figure 8-6 Hylike water storage in litres for the three selected water supply time series and the water demand Scenario 1.

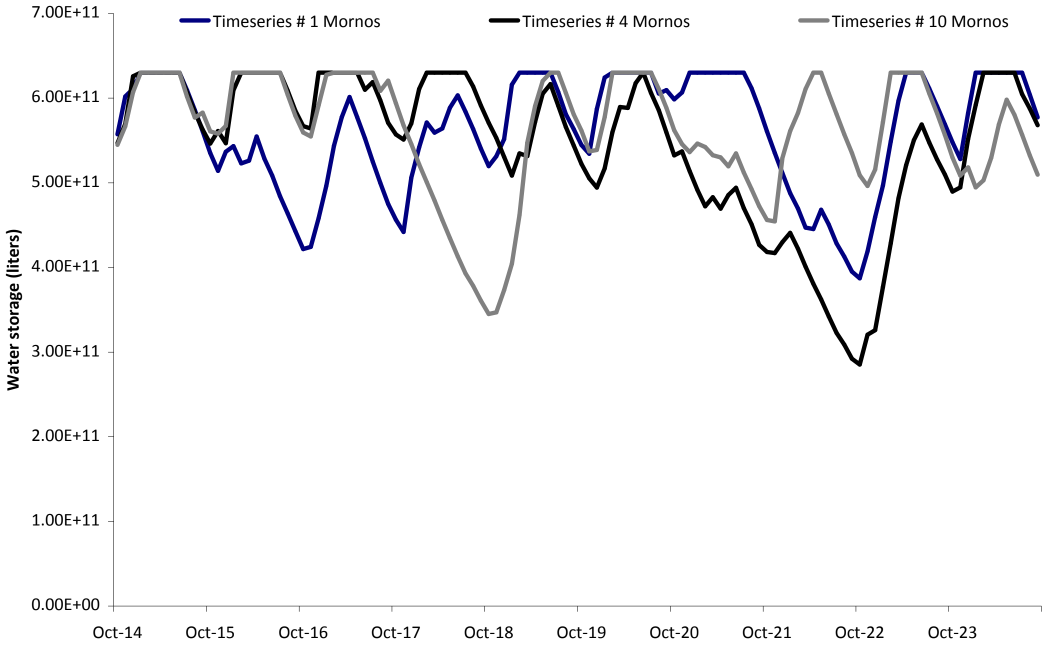


Figure 8-7 Mornos water storage in litres for the three selected water supply time series and the water demand scenario 1.

8.2.2. Scenario 2: Increase of water demand (450 hm^3)

Table 8-2 presents the mean frequencies of use for each appliance, estimated to allow UWOT to simulate the water demand of Athenian households that adds up to a total water withdrawal from the water treatment plants of 450 hm^3.

Table 8-2 Mean Frequency of Use (times per day) for Scenario 2

	Mean Frequency of Use (times per day)								
	Average user			Low user			High user		
	Conservation level:			Conservation level:			Conservation level:		
Appliance	No	Low	High	No	Low	High	No	Low	High
Kitchen sink	3.18	2.77	2.35	3.17	2.76	2.35	3.19	2.77	2.36
Hand basin	5.30	4.82	3.71	5.29	4.81	3.7	5.31	4.83	3.71
Dish washer	0.21	0.21	0.21	0.09	0.08	0.08	0.34	0.33	0.33
Toilet	7.41	6	4.97	7.38	5.98	4.94	7.45	6.03	4.99
Washing machine	0.27	0.26	0.25	0.06	0.05	0.05	0.49	0.47	0.45
Shower	0.77	0.76	0.63	0.55	0.54	0.45	0.98	0.97	0.81
Outdoor uses	0.49	0.38	0.11	0.46	0.35	0.1	0.53	0.41	0.12
Mean monthly water demand (l/p/d)	190	171	142	152	133	108	229	208	176

The estimated water demand, using the UWOT model, was used to produce water bills for the household agents using the tariffs of December 2013. UWAB model ran for ten times without any water demand management strategies in place and the mean value of the results was combined with the results of UWOT. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Figure 8-8 and Figure 8-9 present the reaction to the water demand Scenario 2 of the two main water supply reservoirs, Hylike and Mornos for the three water supply time series (number 1, 4 and 10) with low water availability. The reaction of the hydrosystem is satisfactory without any failures present.

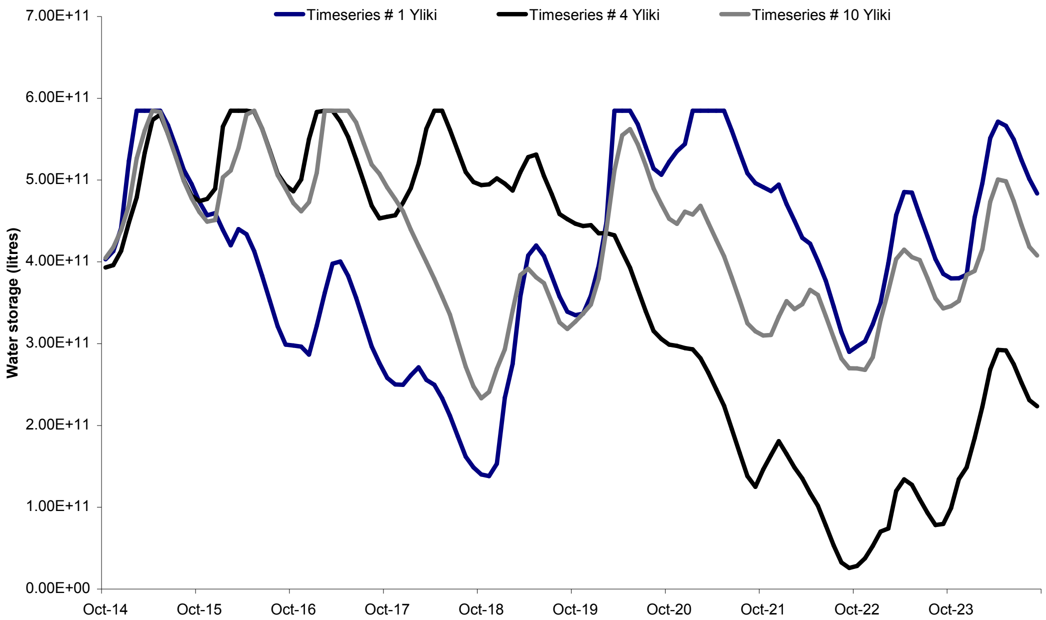


Figure 8-8 Hylike water storage in litres for the three selected time series and for water demand Scenario 2

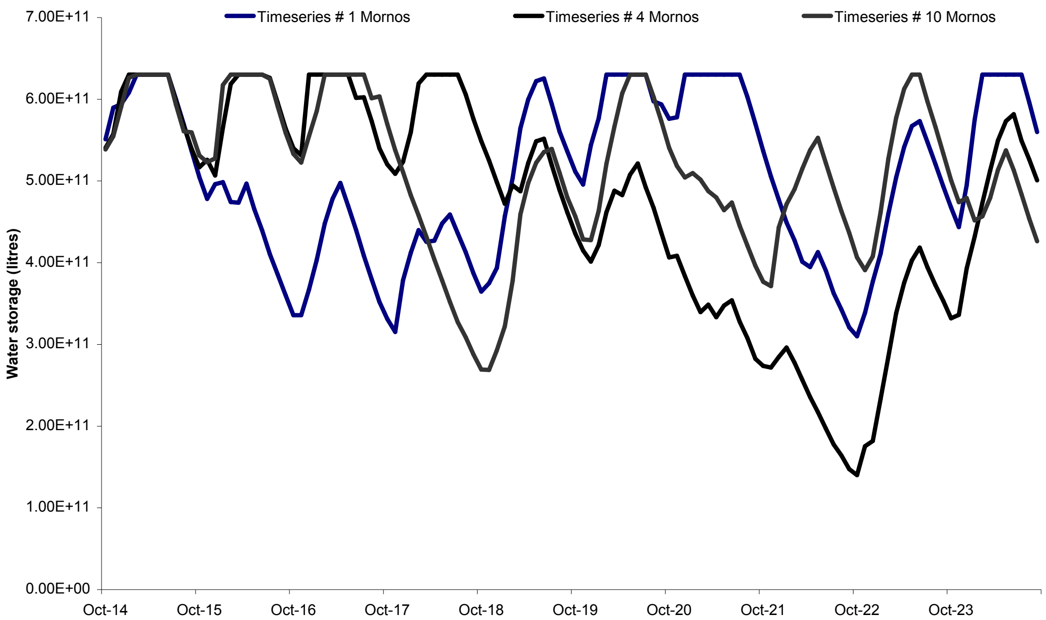


Figure 8-9 Mornos water storage in litres for the three selected time series and for water demand Scenario 2.

8.2.3. Scenario 3: 7% increase of population (480 hm^3)

A 7% increase of population served by EYDAP S.A. corresponds to a total population of 3.447.333 people. The Greek Statistical Office's 2011 census identified that 28% of Athens households have one member, 29% of Athens households have two members, 21% of Athens households have three members, 18% of Athens households have four members and the remaining 4% of Athens households have five or more members. The distribution of household members in Athens allows the conversion of the 3.447.333 people to approximately 1.430.000 households. For this scenario UWAB uses the setup of the previous scenario of increased water demand (Scenario 2) and increases the household agent population to 1430 household agents. UWAB model ran for ten times without any water demand management strategies in place but with the household agents' water conservation attitude influenced by drought conditions and their social network, and the mean value of the results was combined with the results of UWOT. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Figure 8-10 and Figure 8-11 present the response of Hylike and Mornos reservoirs to the three low water supply scenarios and the increased population. In water supply time series #4 the Hylike reservoir fails to provide the water demanded, resulting in 1350 million litres of unmet demand in September 2022.

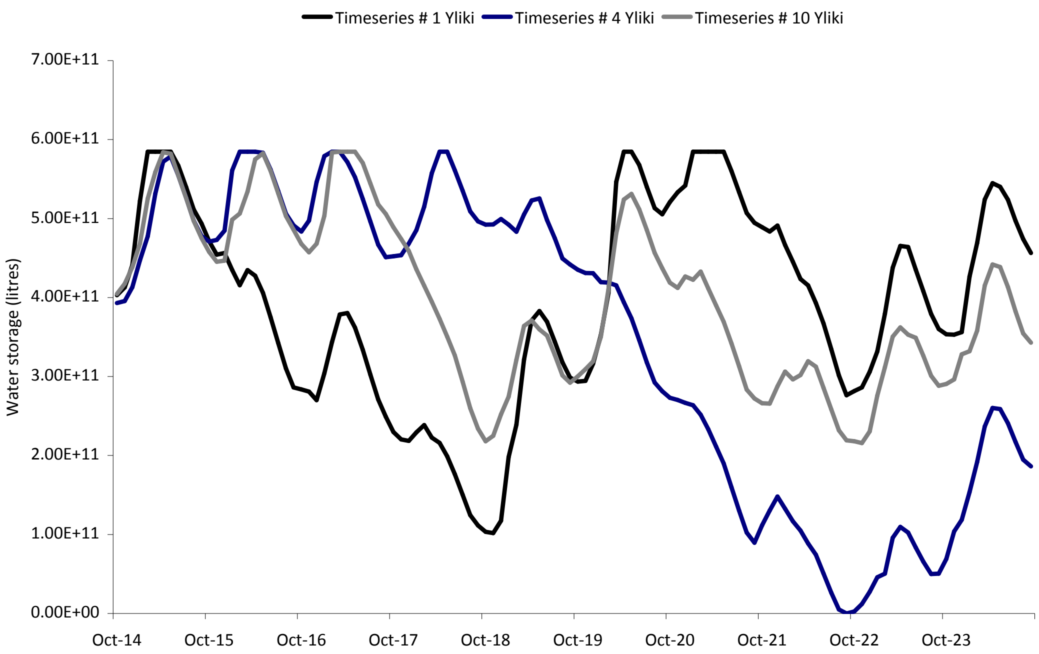


Figure 8-10 Hylike water storage in litres for the three selected time series and for water demand Scenario 3.

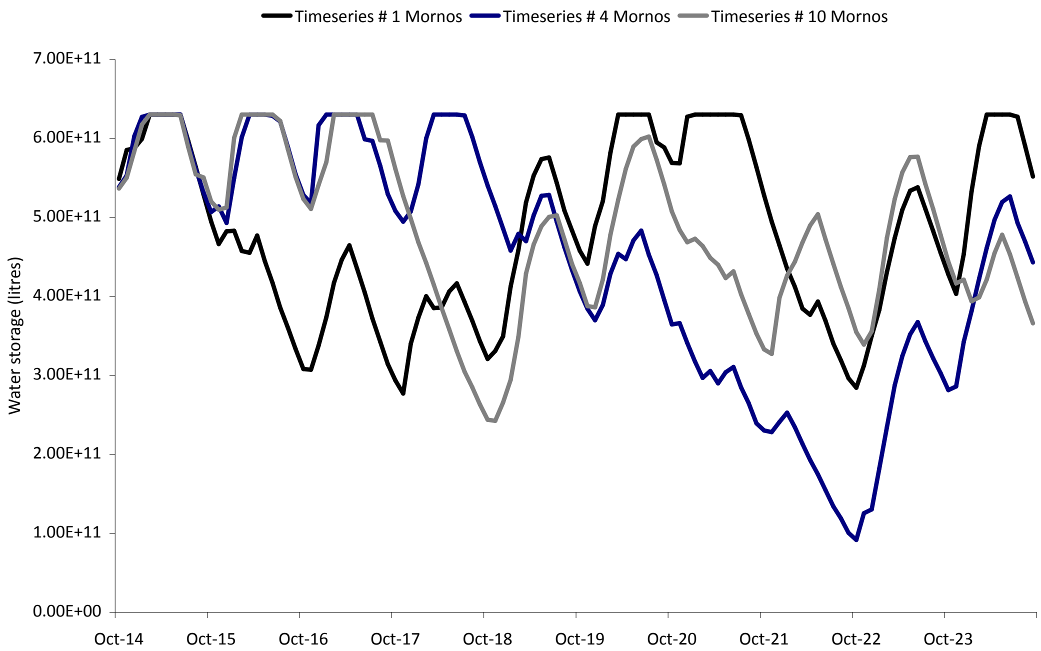


Figure 8-11 Mornos water storage in litres for the three selected time series and for water demand Scenario 3.

8.2.4. Scenario 4: 12% increase of population (500 hm^3)

A 12% increase of population served by EYDAP S.A. corresponds to a total of 3.602.212 people, which corresponds to approximately 1,5 million households based on the distribution of household members in Athens. For this scenario UWAB uses the setup of the scenario 2 of increased water demand and increases the household agent population to 1500 household agents. UWAB model ran for ten times without any water demand management strategies in place and the mean value of the results was combined with the results of UWOT. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Figure 8-12 and Figure 8-13 present the response of Hylike and Mornos reservoirs to the three low water supply scenarios and for increased water demand and Athens population. In water supply scenario # 4 the Hylike reservoir fails to provide the water demanded, resulting in 13.700 million litres of unmet water demand in August 2022 and 708 million litres of unmet water demand in September 2022.

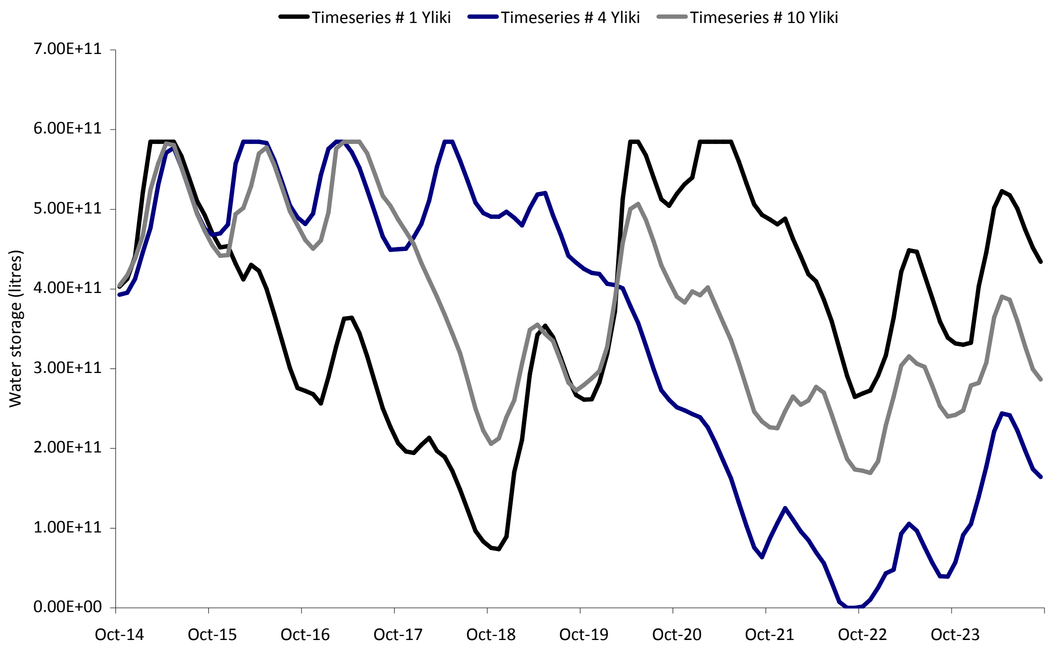


Figure 8-12 Hylike water storage in litres for the three selected time series and for water demand Scenario 4.

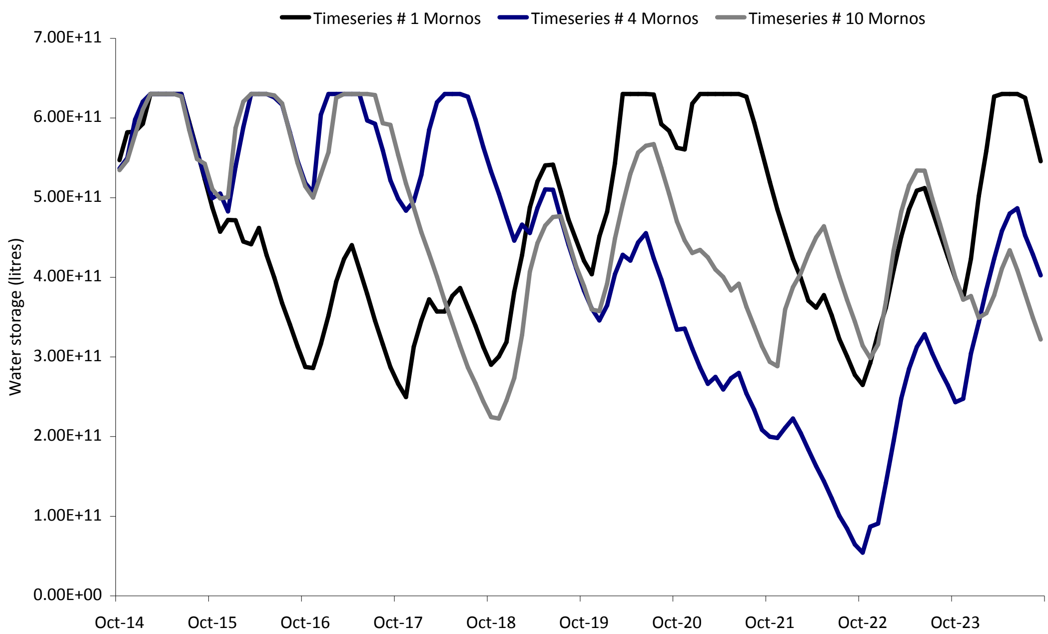


Figure 8-13 Mornos water storage in litres for the three selected time series and for water demand Scenario 4.

8.2.5. Scenario 5: 20% increase of population (550 hm^3)

A 20% increase of population served by EYDAP S.A. corresponds to a total of 3.944.438 people, which corresponds to approximately 1,64 million households based on the distribution of household members in Athens. For this scenario UWAB uses the setup of the scenario of increased water demand and increasing the household agent population to 1640 household agents. UWAB model ran for ten times without any water demand management strategies in place and the mean value of the results was combined with the results of UWOT. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Figure 8-14 and Figure 8-15 present the response of Hylike and Mornos reservoirs to the three low water supply scenarios and for increased water demand and Athens population. In water supply scenario # 4 both the Hylike and Mornos reservoirs fail to provide the water demanded, resulting in a total of 62.900 million litres of Hylike's unmet water demand from June to September 2022 and a total of 27.200 million litres of Mornos' unmet water demand during September and October 2022 (Figure 8-16).

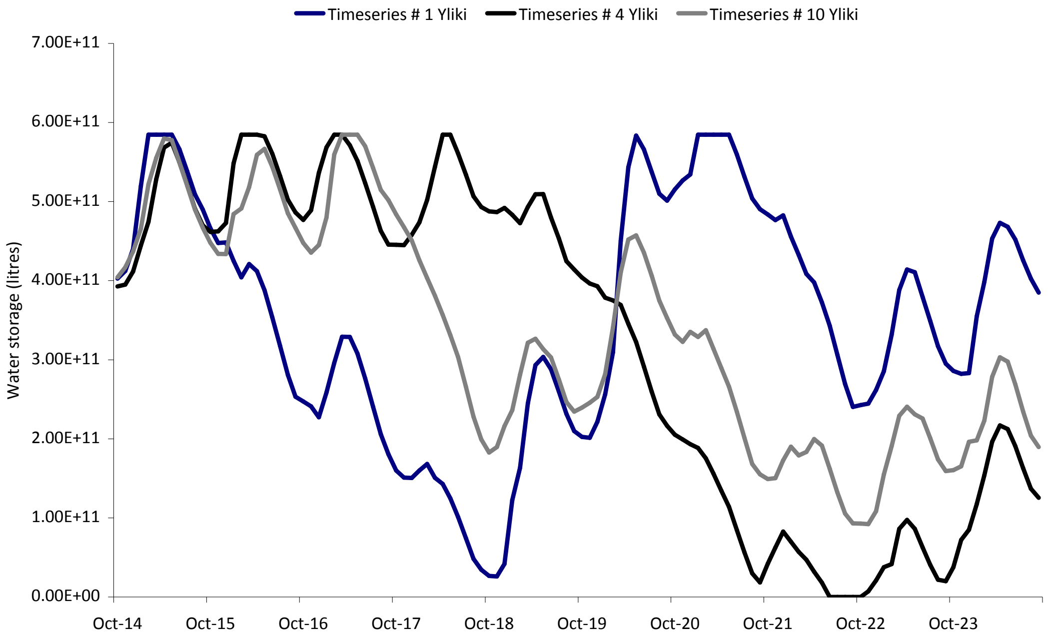


Figure 8-14 Hylike water storage in litres for the three selected time series and for water demand Scenario 5.

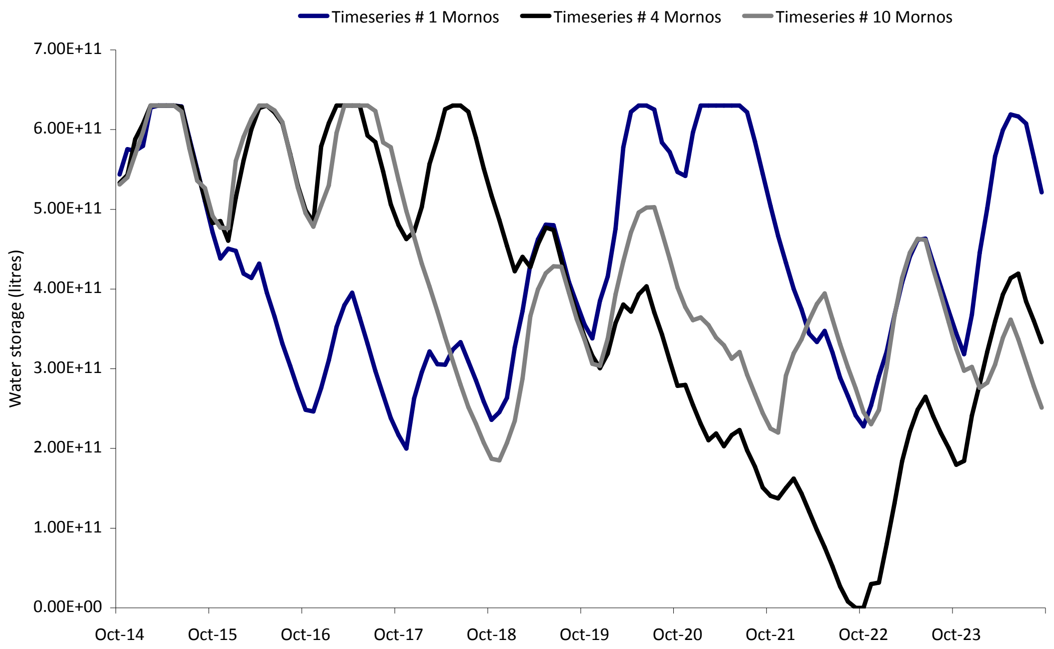


Figure 8-15 Mornos water storage in litres for the three selected time series and for water demand Scenario 5.

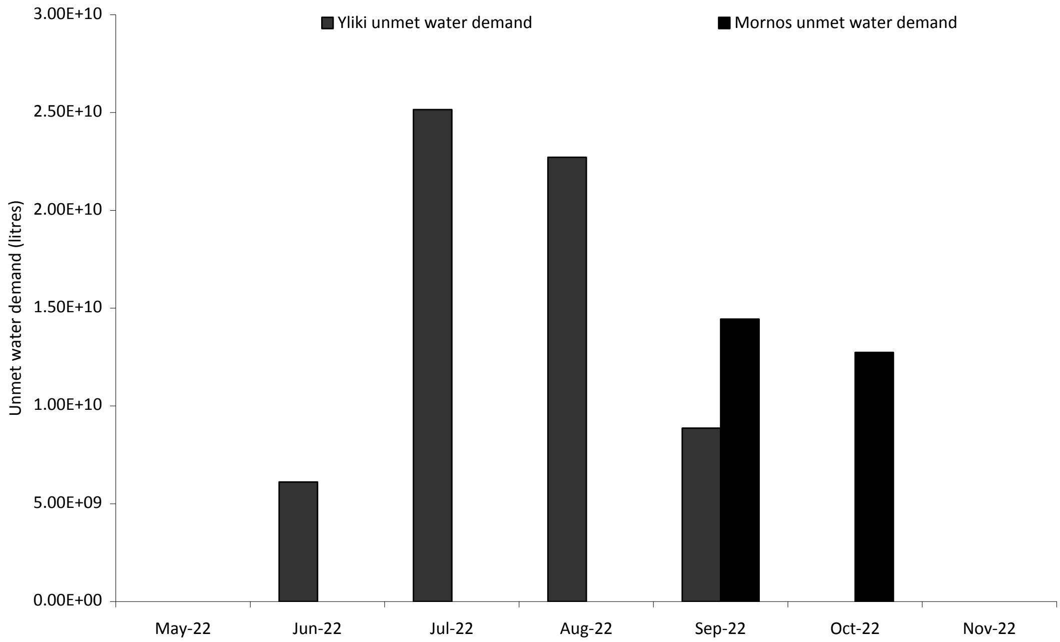


Figure 8-16. Unmet water demand for Hylike and Mornos reservoirs for the water supply time series #4 and for the water demand Scenario 5.

8.3. Testing alternative water demand management strategies

The combinations of water demand scenarios and water supply time series that presented failures to meet the required demand were selected to assess the effect of water demand management strategies on the performance of the urban water system (Table 8-3).

Table 8-3 Water demand scenarios assessment based on the water supply time series

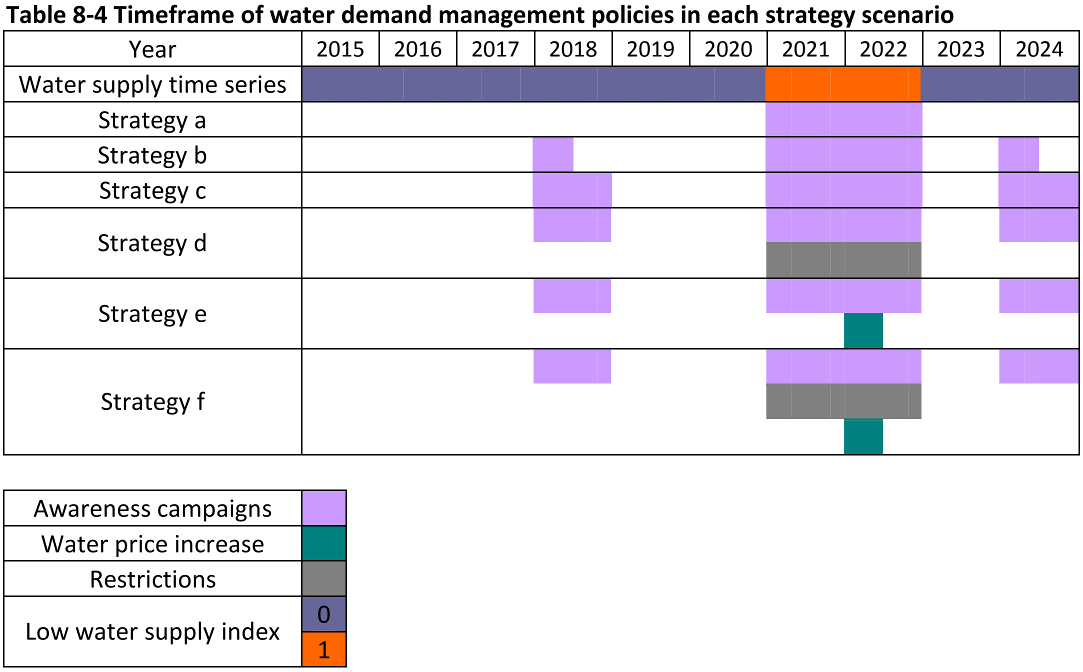
Water demand scenarios	Description	Water demand (hm^3)	Water supply time series 1	2	3	4	5	6	7	8	9	10
Scenario 1	Baseline	370	√	√	√	√	√	√	√	√	√	√
Scenario 2	Increase water demand	450	√	√	√	√	√	√	√	√	√	√
Scenario 3	7% population increase	480	√	√	√	+	√	√	√	√	√	√
Scenario 4	12% population increase	500	√	√	√	+	√	√	√	√	√	√
Scenario 5	20% population increase	550	√	√	√	+	√	√	√	√	√	√

√ represents that the water demand volume was met
+ represents that the water demand volume was not met

These were water demand scenarios 3, 4 and 5 for the 4th water supply time series. The water demand management strategies are implemented to those "challenging" water demand scenarios and for that specific water supply time series.

In the following paragraphs seven experiments of water demand management strategies are investigated using UWAB. Table 8-4 presents the assessed strategies and how they combine different policies in time. The simulation ran, with a monthly time step, from October 2014 to September 2024.

Table 8-4 Timeframe of water demand management policies in each strategy scenario



8.3.1. WDM on Scenario 3: 7% increase of population (480 hm^3)

Figure 8-17 illustrates the behaviour of the Hylike reservoir (which failed in the do nothing scenario) for water demand management strategies b and c. Figure 8-18 zooms to the July-November 2022 and presents the water storage volume for the three WDM strategies: a, b and c. While strategy b did not manage to keep the hydrosystem from failing, unmet volume of water demand was decreased by 12% (1350 to 1190 million litres). However, strategy c managed to meet all the requested water demand, showing the importance of using awareness campaigns as a precautionary measure to increase water saving awareness, resulting in significant – and in this case adequate - water conservation behaviour.

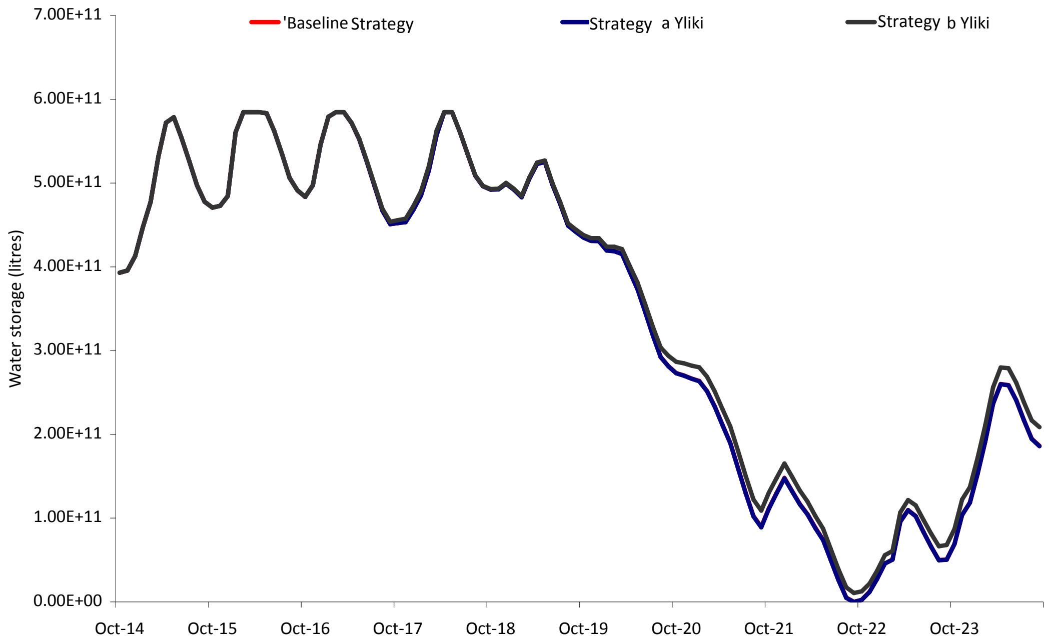


Figure 8-17 Hylike water storage in litres for the selected water supply time series and for water demand Scenario 3 implementing the baseline, a and b water demand management strategies.

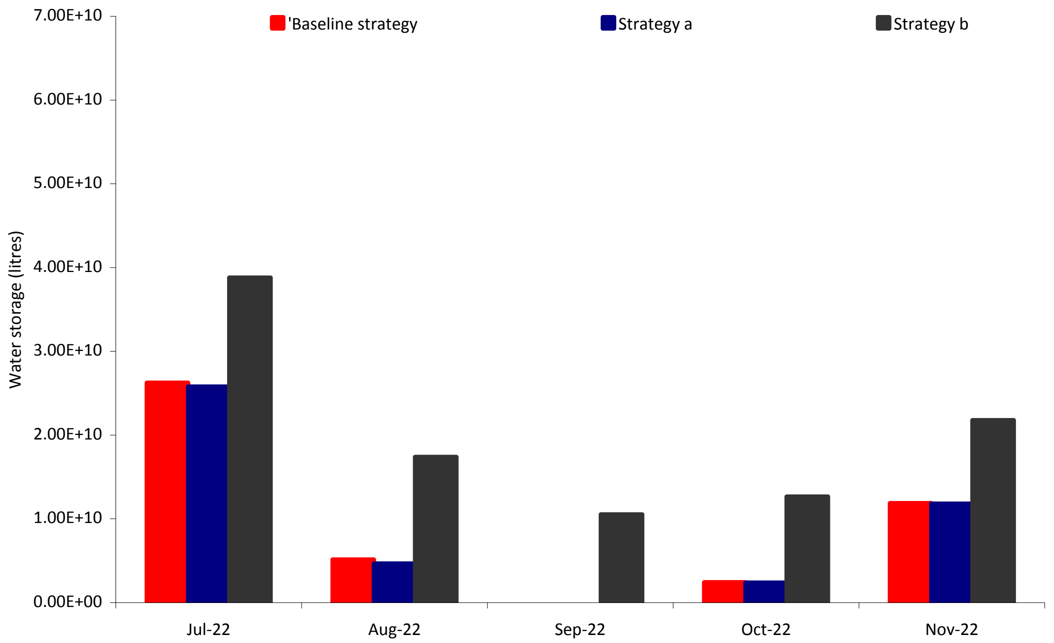


Figure 8-18 July to November 2022 Hylike water storage in litres for the selected water supply time series and for water demand Scenario 3 implementing the baseline, a and b water demand management strategies.

8.3.2. WDM on Scenario 4: 12% increase of population (500 hm^3)

Figure 8-19 illustrates the behaviour of the Hylike reservoir under scenario 4 for all the water demand management strategies. Figure 8-20 zooms to July-November 2022 and presents the water storage volume for the seven strategies.

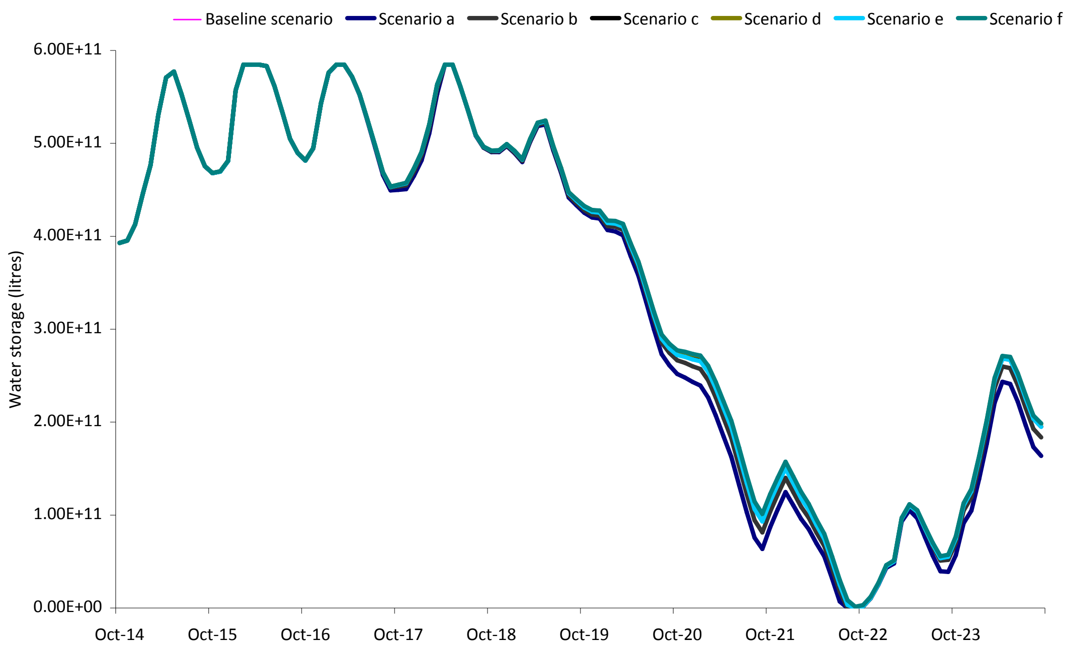


Figure 8-19 Hylike water storage in litres for the selected water supply scenario 4 and for increased water demand, a 12% increase of population and all the water demand management strategies scenarios.

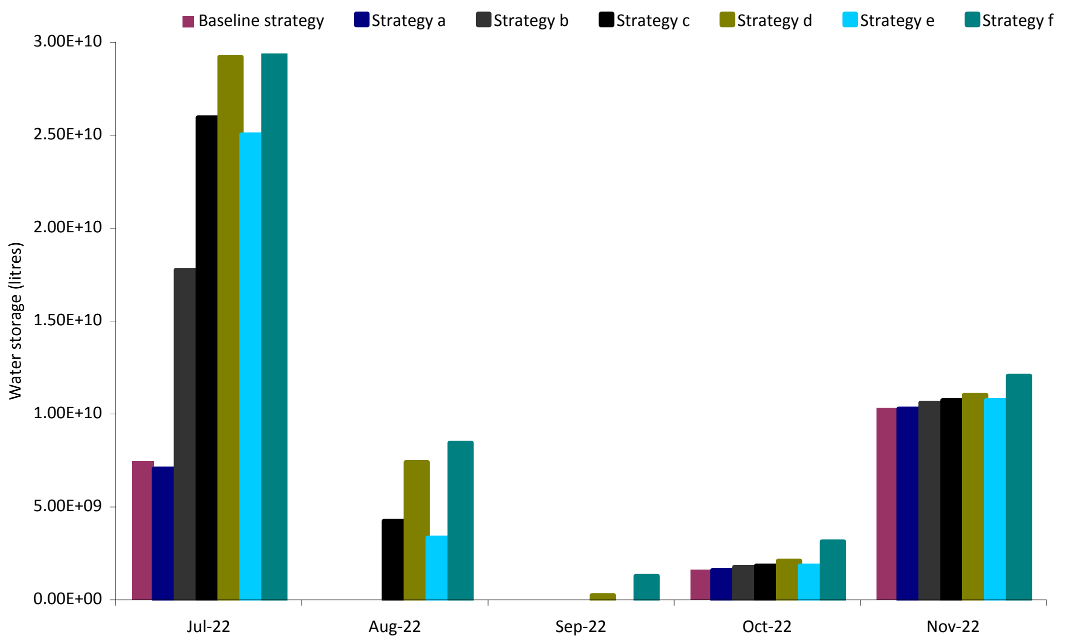


Figure 8-20 July to November 2022 Hylike water storage in litres for the selected water supply time series 4 and for water demand Scenario 4 and for all of the water demand management strategies.

Figure 8-21 presents unmet water demand for each one of the different water demand management strategies. Strategies d and f were able to eliminate unmet water demand. These include restrictions as well as awareness raising campaigns and water price increases.

While strategies b, c and e did not manage to keep the hydrosystem from failing, unmet water demand was decreased as follows:

- **Strategy b** decreased unmet water demand by 73% in August 2022 and by 2% in September 2022
- **Strategy c** decreased unmet water demand by 100% in August 2022 and 60% in September 2022
- **Strategy e** decreased unmet water demand by 100% in August 2022 and 48% in September 2022

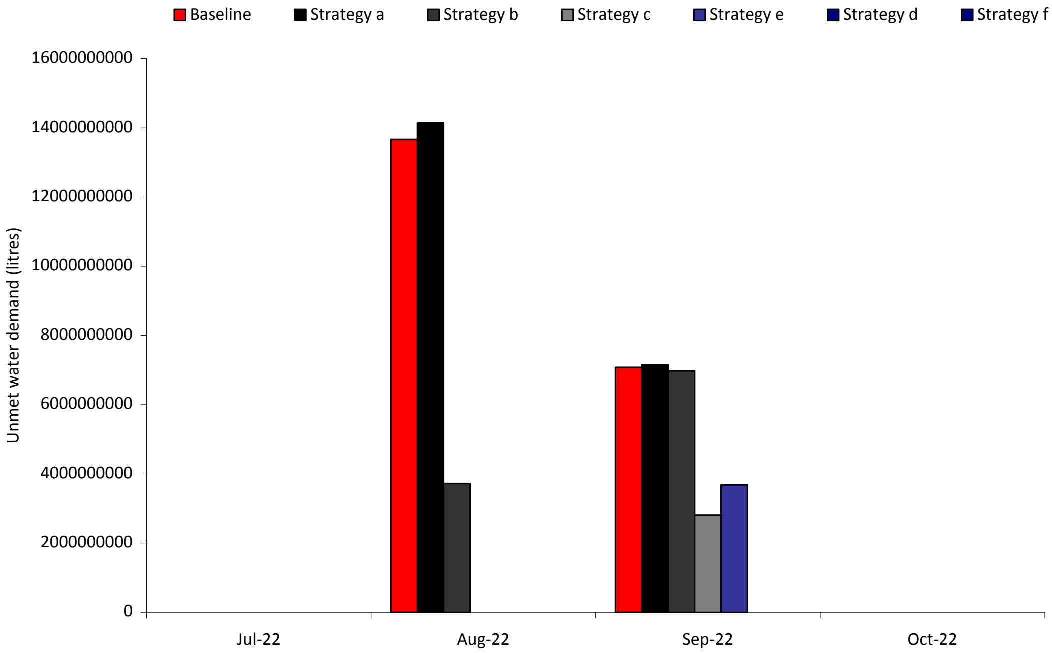


Figure 8-21 Unmet water demand from July 2022 to October 2022 for all the water demand management strategies.

The water price increase in strategy e did not achieve a higher decrease than that of the only awareness raising campaigns of Strategy c. Yet, it is expected from the model's verification and design parameters that a water price change policy will have an additional effect to the water conservation behaviour. In this instance, it is possible to attribute this "anomaly" to the fact that UWAB is parameterised for the Athens drought period.

8.3.3. WDM in Scenario 5: 20% increase of population (550 hm^3)

Figure 8-22 and Figure 8-23 illustrate the behaviour of the Mornos and the Hylike reservoirs for the 4th water supply time series, water demand Scenario 5 and all of the water demand management strategies.

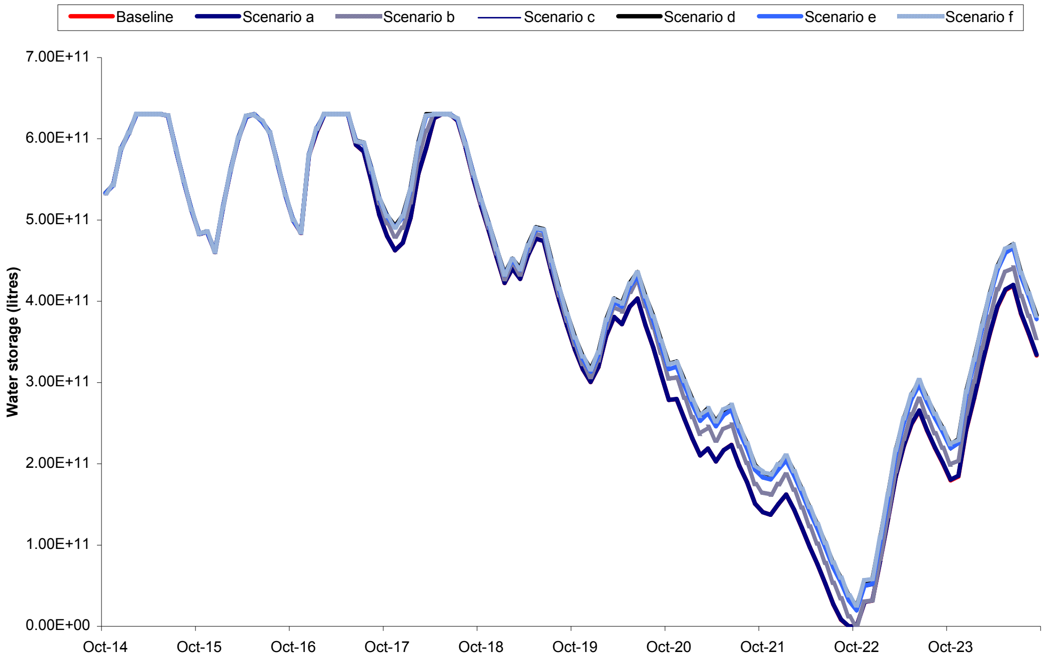


Figure 8-22 Mornos water storage in litres for the selected water supply time series and for water demand Scenario 5 implementing all of the water demand management strategies.

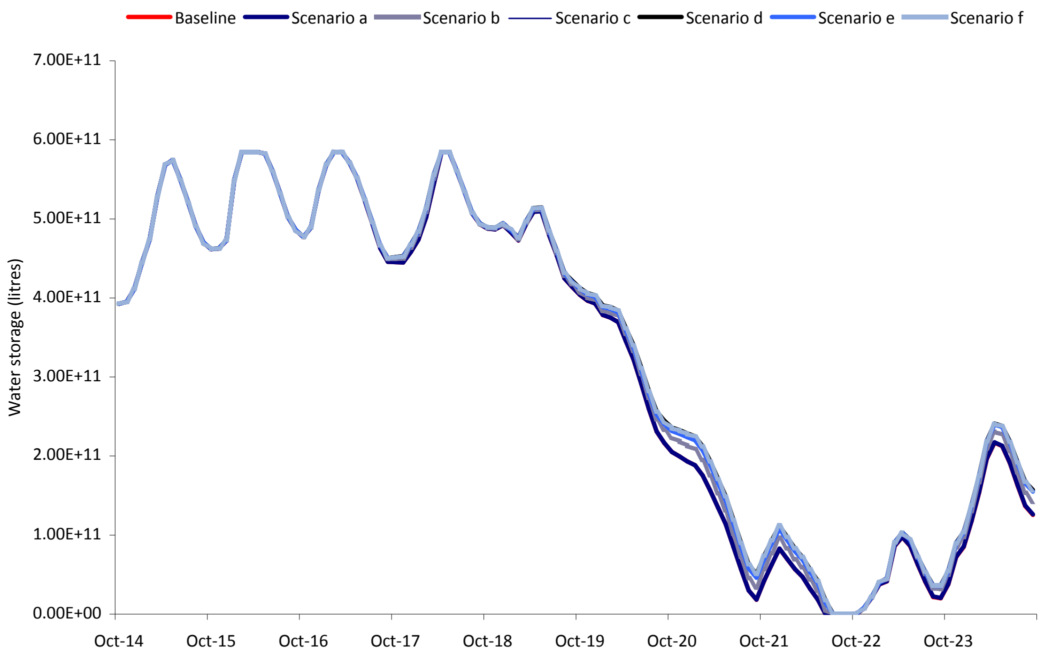


Figure 8-23 Hylike water storage in litres for the selected water supply time series and for water demand Scenario 5 implementing all of the water demand management strategies.

Figure 8-24 and Figure 8-25 zoom in to July-November 2022 for Mornos and Hylike respectively and present the water storage volume for the seven experiments: baseline and water demand management strategies a, b, c, d, e and f.

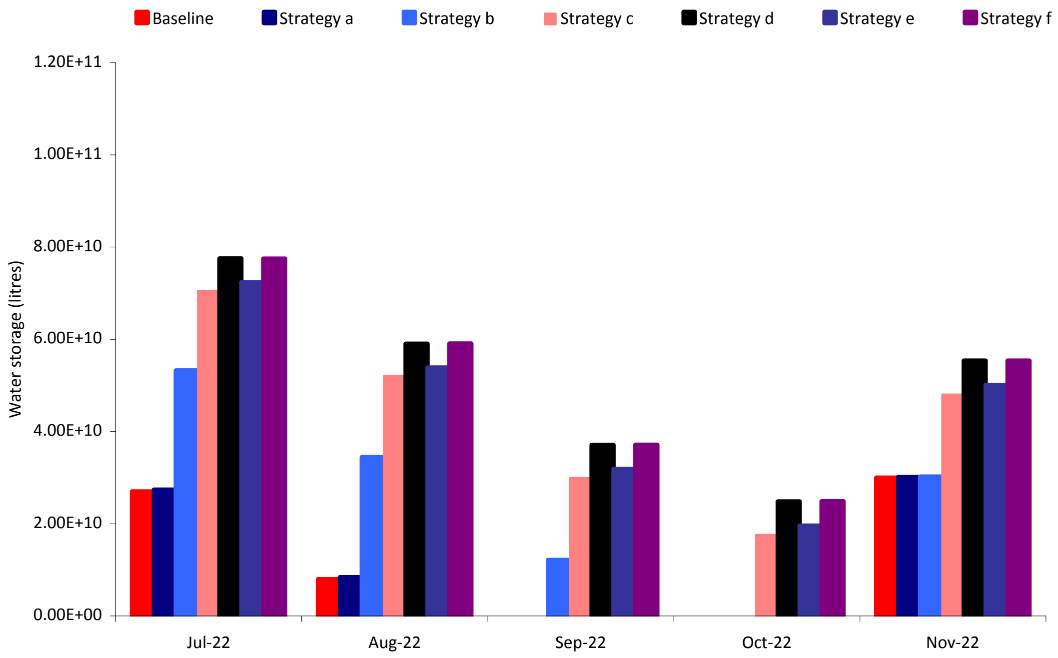


Figure 8-24 July to November 2022 Mornos water storage in litres for the selected water supply time series and for water demand Scenario 5 implementing all of the water demand management strategies.

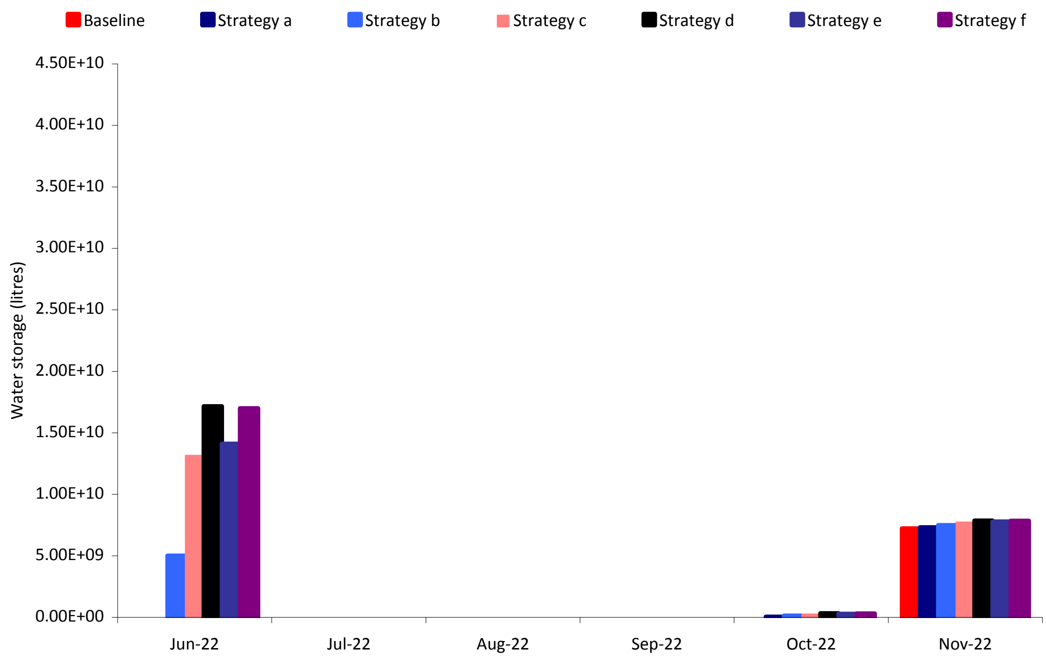


Figure 8-25 July to November 2022 Hylike water storage in litres for the selected water supply time series and for water demand Scenario 5 implementing all of the water demand management strategies.

Figure 8-26 and Figure 8-27 present the unmet volume of water demand in litres for the different water demand management strategies.

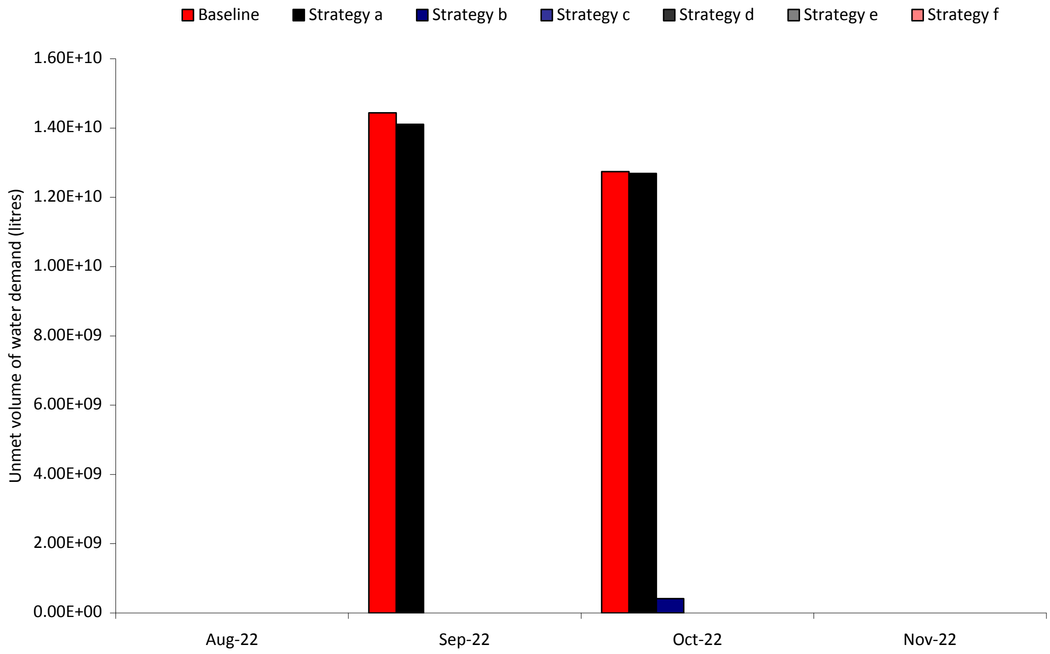


Figure 8-26 Unmet volume of water demand in litres from Mornos reservoir.

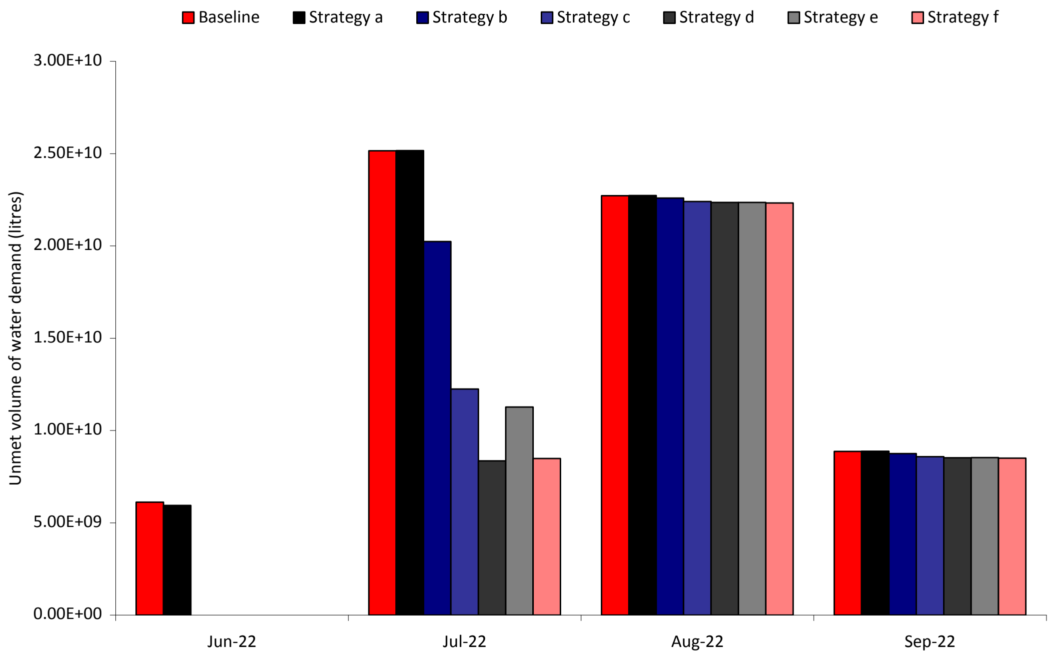


Figure 8-27 Unmet volume of water demand from Hylike reservoir

While none of the strategies managed to keep the hydrosystem from failing, the unmet water demand was decreased as follows:

- **Strategy a** decreased average unmet demand by 1% for both reservoirs

- **Strategy b** decreased average unmet demand by 98% for Mornos reservoir and 30% for Hylike reservoir

- **Strategy c** decreased average unmet demand by 100% for Mornos reservoir and 39% for Hylike reservoir

- **Strategy d** decreased average unmet demand by 100% for Mornos reservoir and 43% for Hylike reservoir

- **Strategy e** decreased average unmet demand by 100% for Mornos reservoir and 40% for Hylike reservoir

- **Strategy f** decreased average unmet demand by 100% for Mornos reservoir and 43% for Hylike reservoir

Yet again, as in the previous Scenario 4, the precautionary use of awareness raising campaigns decreases the unmet volume of water demand and that the duration of the campaign is an important factor of the UWAB model. In the model's real world application it is suggested that water companies can use UWAB to calculate the duration of this campaign and associate it with drought indicators as means to initiate timely water demand management measures. The water price change strategies do not achieve a substantially higher decrease than that awareness raising campaign strategy c or awareness campaigns and restrictions strategy d.

None of the selected water demand management strategies was able to alleviate the effects of the increased water demand that was brought by a 20% increase of the population. However, the tested strategies did not account at all the possibility of reducing other types of water demand such as commercial, municipal, untreated, industrial or other that correspond to 22% of the total water demand of Athens. In addition, these strategies have not taken into consideration a decrease in the water lost by the distribution system which corresponds to 28% of the total water demand of Athens. With these in mind, it could be possible to alleviate effects of as much as 20% increase of the served population if policies are implemented that also aim in the reduction of other types of water demand and/or water losses.

Figure 8-29 shows the decrease of the volume of unmet water demand for each water demand management strategy.

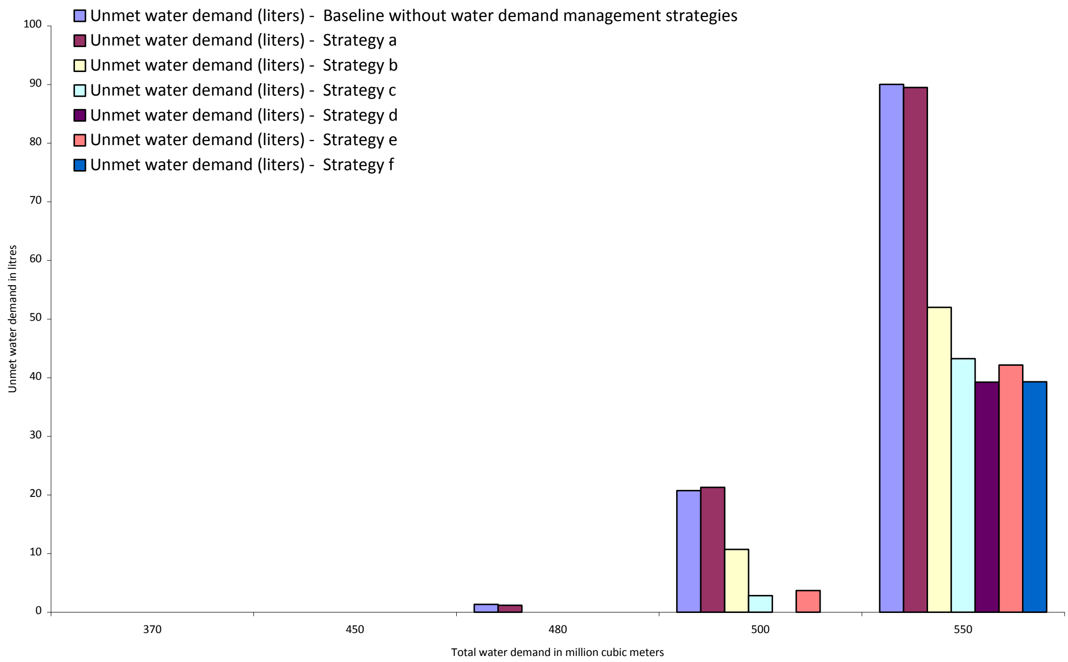


Figure 8-29 Unmet water demand for the selected water supply time series number 4 for each water demand scenario and water demand management strategy

The results demonstrate that it is possible to use the UWAB-UWOT modelling platform to simulate the effects of different water demand management strategies to the urban water system.

8.4. Summary

The aim of this chapter was to assess the ability of the developed UWAB-UWOT modelling platform to investigate the response of the hydrosystem to different water demand scenarios and water demand management strategies. The scenarios examined illustrate the necessity to use awareness campaigns proactively to avoid water supply shortage even in cases of drought. However, a further increase of the population and persistence in drought conditions may require more strict measures.

The results illustrate the usability of the platform to support decision makers in applying a more adaptive urban water management approach. Using the platform the decision maker is be able to identify not only how “strict” water demand management measures are needed to alleviate water supply potential issues but also when and for how long to deploy them.

Chapter 9. Conclusions

"It is good to have an end to journey towards;
but it is the journey that matters in the end."
Ursula K. Le Guin,The left hand of darkness

9.1. General Conclusions

The urban water system is a complex adaptive system consisting of technical, environmental and social components which interact with each other through time. As such, its investigation requires tools able to model the complete socio-technical system, complementing "infrastructure-centred" approaches. This research:

- **Developed an agent based modelling tool**, the Urban Water Agents' Behaviour (UWAB) model, for assessing the domestic water demand behaviour under different external drivers of influence such as demand management policies and weather conditions. UWAB design is based on a fusion of several different theories:

    - The social environment, within which the household agents operate, is conceptualised as a scale-free network

    - The influence exerted to the water demand behaviour of the households is simulated following Social Impact Theory

    - Theory of Planned Behaviour is used to create the rules of water demand behaviour that include all key shaping factors of domestic water demand such as: the environmental consciousness level; the socio-demographic characteristics (age, income, education, housing type); the past water saving behaviour; the social network impact; the awareness of drought conditions; the perceived ease or difficulty to decrease water demand; the effect of past water saving behaviour to the water bill; and the effect of imposed water restrictions

    - The final behaviour of the agents is decided using statistical mechanics to incorporate stochasticity in the simulation of the agents' final decision.

- **Used an existing urban water cycle management tool**, the Urban Water Optioneering Tool (UWOT), to assess the evolution of the urban water system under water demand behaviour changes. The translation of the household's behaviour to water demand volumes is undertaken by coupling UWAB with a state of art water demand management model (UWOT). UWOT calculates the water demand of a household based on the frequency of use of each household appliance provided by UWAB.

- **Created a modelling methodology** for integrating UWAB with UWOT to calculate the evolution of domestic water demand by simulating the use of water appliances.

- **Assessed the effectiveness and usability of the proposed modelling platform** by exploring both its ability to recreate a historical event and to explore the effects of different scenarios on an urban water system. To assess the modelling methodology, we used:

    a. The state of art on water demand shaping factors, adaptive urban water management and water demand management strategies

    b. Social research methods, used to understand behavioural and attitudinal concepts of domestic urban water demand

- **The UWAB-UWOT modelling platform was tested by using a historical event.** The method and tools are applied to the Athens 1988-1994 drought and evaluated regarding their ability to recreate the influence of historic water demand management strategies on the actual water demand behaviour of Athenian households, as recorded in water demand data of the EYDAP SA.

- **The UWAB-UWOT modelling platform was applied** to investigate the effect of alternative hypothetical water demand management strategies for the Athens urban water system, under a variety of supply-demand scenarios. The calibrated platform was subsequently used to assess alternative water demand management strategies simulating their effects on the urban water system of Athens under a variety of supply-demand scenarios.

- **The results suggested that the coupling of the two models provides new functionality for water demand management strategies design and assessment by water regulators and companies.** Specifically it gives the opportunity to better understand the way the system may react to water demand management strategies and supports the identification of appropriate parameters for the strategies' deployment (such as their intensity, duration and initialisation time).

- **It is concluded that water demand management requires the understanding of society's water demand behaviour and the way policy measures affect it.** Water managers and policy makers need to reconnect with water users, regain their trust and aim at creating a conceptual link from the household's tap to the water resource in the citizen's consciousness which may eventually increase water saving behaviours. This work provides some of the tools needed to understand, manage and improve this vital connection.

9.2. Contributions to the state-of-art

"It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be."

Isaac Asimov

The research undertaken within this PhD is multidisciplinary, since it involves working at the interface of different scientific disciplines, sociology, hydrology, water engineering and computer science. The ultimate goal of was to create a tool for supporting a more adaptive, approach to urban water resources management able to include interactions across the complete socio-technical system.

A main challenge and motivation for the work was a gap that exists in the state of art in terms of theories and models able to quantify water demand behaviours. The field of behaviour falls within the domain of social psychology, but most of the related theory is of a more descriptive rather than computational nature. To be able to encapsulate characteristics, attitudes, interactions and behaviours within a modelling framework, four theories were employed in combination this research: complex network theory, Social Impact Theory, Theory of Planned Behaviour and statistical mechanics. These have as common denominator their ability to quantify the social phenomena in question.

Additionally, an online survey was used to gather information regarding the frequency of use of different water appliances and for different water conservation levels. Even though all the results of the online survey could not be used as such, the percentage difference between the no, low and high conservation levels was indeed used. supported by a qualitative social research study to verify water conservation behaviour rules of the agents. This work although not novel methodologically, is the only of its kind in Greece and provides (together with a companion survey (Koutiva et al., 2015) a preliminary evidence base for water conservation attitudes and behaviours in Southern Europe.

The main contributions to the state-of-art are summarised below:

i. A **novel modelling tool** (UWAB) was presented and tested. UWAB simulates the water demand behaviour of urban households. The household agent behaviour is an emergent property, caused by the interaction of the household agents and their decision rules. The model is underpinned by a set of novel decision rules, based on both literature review and a qualitative social research study. UWAB successfully reproduces historical events and is able to evaluate future scenarios.

ii. A **new methodology** to combine the results of UWAB with existing urban water management tools was developed to support a more adaptive approach to water resources management. Although the method was tested with UWOT, it was developed in a flexible, loose coupling way to allow for its future modification in combination with other water management tools (e.g. Hydronomeas, Acquacycle etc).

iii. A **new methodology** for translating the results of the UWAB model into domestic water demand was also developed. The results of the UWAB model present the water conservation behaviour of the agents in a form (number of household agents per water conservation level and per water user type) that may be used for validation purposes answering questions like "does the model behave as expected?". The model's results show that the household agent population reacts in a "common sense" way, meaning it reconsiders its water conservation behaviour when signals are sent regarding water prices changes and awareness campaigns and forgets about water saving, returning to its common use, when policies are not in place. This "looking right" model results indicate a sign of model verification. These results however are not "usable" for the decision maker since they do not provide an actual numerical value of the water demand evolution. Therefore, they require transformation to monthly water demands using (in this case) the UWOT model. UWOT accepts appliances' frequencies of use from UWAB to create time series of monthly water demand. These frequencies of use include any annual or seasonal variations and are different for the different water user types and conservation levels. This approach is both new and novel offering significant flexibility and information richness.

iv. A **novel calibration methodology** for agent based models was developed and tested by combining the ABM model with a multi-objective genetic algorithm minimising two objective functions, that attempt to improve the performance of the model in view of being able to capture the fluctuations of (historic) water demands due to (historic) water policies.

v. The work enables a **completely new way** of designing, evaluating and managing **water demand management strategies.** UWAB provides the possibility to test the effect of **water demand management strategies** implemented for different durations and frequencies allowing the user (i.e. water company or policy maker) to learn and adapt.

The key contribution of the work is that it presents an novel alternative methodology to simulate the water demand behaviour of urban households taking into consideration both technical (frequencies of use of different water appliances) and social (influences from social network, policies etc) characteristics of the social dimensions of the urban water system. This is a significant advance against the most common approach to date which was to include within water management tools a time series of water demands that were produced either by extrapolating from historical trends or by applying simplified assumptions (of the fixed % reduction or increase type) to derive future demands. The potential to explicitly simulate domestic water demand behaviour as part of a complete socio-technical system modelling for urban water management has been a major goal of hydroinformatic research for several years (Price, 2011).

The research resulted in several scientific publications that are included in Annex V.

9.3. Further research

"You can't really predict the future. All you can do is invent it."
Frederik Pohl

There are several potential avenues to take the research developed herein forward:

A next step would be to use UWAB in another case study that would allow the parameterisation of the model with more data and fewer assumptions. Although such cases rarely exist, it is suggested that the development of models like UWAB provides a demand pull for work into quantifiable characteristics of demand and as such promotes further research into the interfaces between engineering and social science.

With respect to UWAB model design, future research may allow the expansion of the model by creating different "breeds" of agents that could correspond to households of different municipalities, inheriting the socio-demographic of the different areas of a city. This expansion would be able to include geographic information, and take into account more population characteristics, such as ethnicity, to create the network of social impact. The results of this expanded UWAB model could be linked with the UWOT and provide a more comprehensive water demand for the different drinking water treatment plants of a city, wherever this is applicable.

Regarding the UWAB-UWOT integration, future research may focus on linking these two models dynamically to allow the calibration of frequencies of use for the different household appliances. This could significantly speed up the data exchange and overall runtime performance of the modelling platform – admittedly with loss of flexibility as suggested above.

Work on improving UWAB-UWOT modelling platform usefulness could also focus on end user studies, also benefiting from results from smart-metering deployments (Makropoulos et al., 2014) that could provide better estimates of the frequency of use of different appliances including annual and seasonal variations. Such information is required to create more realistic future scenarios of water demand and testing water demand management strategies.

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Annex I - UWAB state variables

Experimental variables that were used for the sensitivity analysis and the calibration of the modelling platform are given in bold.

Social characteristics

Variable	Setup of parameter	Brief Description
Income level (i) income E {-1, 0, 1, 2}	Require data from statistical offices for the distribution of income levels within the population.	Income level of the household agent (-1 = low level, 0 = low – middle, 1 = middle – high, 2 = high)
Age level (a) age E {-1, 0, 1}	Require data from statistical offices for the distribution of age levels within the population.	Age level of the household agent (-1 = 19-34, 0 = 35 – 64, 1 = => 65)
Education level (e) edu-level E {-1, 0, 1}	Require data from statistical offices for the distribution of education levels within the population.	Education level of the household agent (-1 = low, 0 = middle, 1 = high)
Household occupancy (ho) occupancy E {1, 2, 3, 4, 5}	Require data from statistical offices for the distribution of family sizes within the population.	Number of household members of the household agent
Housing type (renting or owning) (ht) housing E {0, 1}	Require data from statistical offices for the distribution of housing types within the population.	Housing type of the household agent (0 = renters, 1 = owners)
Environmental consciousness (ea) envaware E {-2, -1, 0, 1, 2}	Require data from statistical offices for the distribution of environmental consciousness levels within the population.	Environmental consciousness level of the household agent (-2 = very low environmental consciousness, -1 = low environmental consciousness, 0 = middle environmental consciousness, 1 = high environmental consciousness, 2 = very high environmental consciousness)

Water demand management policies

Variables	Setup of parameter	Brief description
water_bill_a water_bill_b	Requires information from UWOT	Household agents receive every three months a water bill based specific to their water user type, water

		conservation level and the size of their household. The comparison between water bills allows the household agents to review their decision regarding the water conservation level.
price_change_info E (-1, 0, 1)	If a historical event is under investigation this is set based on the historical information available. If scenarios of domestic water demand evolution are explored this is set to explore different water pricing policies.	The information on water price change (-1 = decrease of water price, 0 = stable water price, 1 = increase of water price) creates an extra positive or negative influence towards water conservation.
Strength of influence regarding price changes mean _strength _influence_price **(S_{PC}) (>= 0)** **sd _strength _influence_price (0.8 * S_{PC})**	**Experimental variable. If a historical event is under investigation this is a calibration parameter. If scenarios of domestic water demand evolution are explored this is set to explore different distributions of the influence strength regarding water price changes.**	**Mean and standard deviation of the distribution of the influence strength within the urban population regarding water price changes.**
onset_pricing end_pricing	If a historical event is under investigation this is set based on the historical information available. If scenarios of domestic water demand evolution are explored this is set to explore different water pricing policies.	Number of ticks (months) since the beginning of the simulation that a pricing policy begins and ends.
Total time of transmitting information regarding water pricing changes months_price_information **(M)**	**Experimental variable. If a historical event is under investigation this is set based on the historical information available. If the information is not available this is a calibration variable. If scenarios of domestic water demand evolution are explored this is set to explore different water pricing policies.**	**Months (number of ticks) before and after a water price change event that the information is still transmitted.**
onset_campaign end_campaign	If a historical event is under investigation this is set based on the historical information available. If scenarios of domestic water demand	Number of ticks (months) since the beginning of the simulation that an awareness raising campaign begins and ends.

Strength of influence regarding awareness raising campaigns mean_strength _influence_awareness _campaigns **(S_{AC}) (>= 0)** sd_strength _influence_ awareness _campaigns **(0.8 * S_{AC})**	evolution are explored this is set to explore different awareness raising campaigns policies. **Experimental variable. If a historical event is under investigation this is a calibration parameter. If scenarios of domestic water demand evolution are explored this is set to explore different distributions of the influence strength regarding awareness raising campaigns.**	**Mean and standard deviation of the distribution of the influence strength within the urban population regarding awareness raising campaigns.**
Awareness_Campaign (0, 1)		Awareness raising campaigns regarding water conservation (0 = no campaign, 1 = campaign) creates an extra positive or negative influence towards water conservation.

Social impact procedure

Variables	Setup of parameter	Brief description
Distribution of positive attitudes towards water conservation %+_water_conservation **(%ipa)**	**Experimental variable. Household agents are randomly assigned positive or negative initial positive attitude towards water conservation.**	**Initial percentage of population with positive attitude towards water conservation.**
Initial attitude opinion-watercons E {-1, 1} (O)	Household agent's decision parameter	Water conservation attitude (-1 = negative towards water conservation, 1 = positive towards water conservation)
Mean strength of influence influence_strength **(>=0) (S)**	**Experimental variable**	**Personal strength of influence sets the level of persuasiveness that a household agent has towards "selling" its attitude regarding water conservation to its social network**
Opinion stubbornness opinion_strength (>=0) (b)	Requires knowledge regarding the society's stubbornness. Set to a constant of 2 based on theory (Kacperski and Holyst, 1999, Bahr and Paserini, 1998, Wragg, 2006).	Personal attitude strength sets the level of stubbornness, measuring the difficulty to change its attitude regarding water conservation.
Distribution of the	**Experimental variable.**	**Percentage of population**

population affected by an external (to the modeled area) source of positive attitudes towards water conservation %+_ext_water_cons **(%epa)**	**Household agents are randomly assigned positive or negative external influence.**	**with positive external influence towards water conservation. Constant throughout the simulation.**
External influence external_influence ∈ {-1, 1} (O_e)	Household agents are randomly assigned positive or negative external influence.	External connections' attitude (-1 = negative towards water conservation, 1 = positive towards water conservation)
Strength of external influence strength-external **(>= 0) (S_e)**	**Experimental variable. Household agents are randomly assigned a strength of external influence sampled from a normal distribution where mean and standard deviation are the experimental variables.**	**External connections' strength of influence sets the level of persuasiveness that the external social connections of the household agent have towards "selling" their attitude regarding water conservation**
Volatility of Social Impact Volatility_SocialImpact **(>= 0) (T)**	**Experimental variable. Constant for all household agents and throughout the simulation.**	**T is the average volatility of social impact. The parameter T is a measure of "social temperature" that captures the susceptibility to change of the average attitude within the simulated population (Kacperski and Holyst, 1999, Bahr and Paserini, 1998). High values of T mean that attitudes are difficult to change and low values that attitudes are highly dependent on social norms (Wragg, 2006).**

Water demand behaviour procedure

Variables	**Setup of parameter**	**Brief description**
low-user? (true/false) high-user? (true/false) mean-user? (true/false)	Requires information regarding the distribution of the water user types within the population.	Each household agent has a type of water user assigned from the beginning of the simulation.
past water saving behaviour (p) E {-2, 1}	This variable tries to capture the effect of familiarity with ones previously implemented behaviour.	Depending on the water conservation level implemented in the previous step. (-2 = no conservation, 1 = low or high conservation level)
watercommonuse E {-1, 1}	This variable is the final outcome of the water demand decision	No, low or high level of water conservation selected.

waterconslowlevel E {-1, 1} waterconshighlevel E {-1, 1}	process.	
water-saving-attitudes E {-2, 1, 2}	Household agents calculate this parameter	This variable indicates the water conservation behaviour of the previous time step (-2 = no conservation, 1 = low conservation level, 2 = high conservation level)
cu-network E {0, 1} lc-network E {0, 1} hc-network E {0, 1}	Household agents calculate this parameter	Shows which type of conservation level covers the majority of a household agent's social network. 0 = minority, 1= majority
drought_signal E {0, 1, 2}	If a historical event is under investigation this is set based on the historical information available. If scenarios of domestic water demand evolution are explored this is set to explore the effect of different drought periods.	Indicates whether or not there is drought (information for this is assumed to be transmitted and the social network and affect all the population).
difficulty_waterdecrease E {-1, 0, 1}	Household agents calculate this parameter	Difficulty in decreasing water demand based on the household agent's water user type (low user = -1, mean user = 0, high user = 1)
Behavioural intention of no water conservation level (BINC)	Household agents calculate this parameter	Calculated using the following function BINC = Network influence - (Environmental Attitude + Social Characteristics (age, income, education, housing conditions) + Drought Conditions Awareness + Ease or difficulty to decrease water demand)
Behavioural intention of low water conservation level (BILC)	Household agents calculate this parameter	Calculated using the following function BILC = Environmental Attitude + Social Characteristics (age, income, education, housing conditions) + Network influence + Drought Conditions Awareness + Ease or difficulty to decrease water demand + Effect of past water saving behaviour favouring

		low conservation + Restrictions effect Calculated using the following function
Behavioural intention of high water conservation level (BIHC)	Household agents calculate this parameter	BIHC = Environmental Attitude + Social Characteristics (age, income, education, housing conditions) + Network influence + Drought Conditions Awareness + Ease or difficulty to decrease water demand + Effect of past water saving behaviour favouring high conservation + Restrictions effect
Restrictions effect (r) E {0, 1, 2}	Depends on the restrictions in place.	Imposing restrictions increase the necessity to decrease water demand. (r = 2 for high conservation, r = 1 for low conservation and r = 0 for no conservation)

Water demand behaviour review procedure

Variable	**Setup of parameter**	**Brief description**
Effect of past water demand state (f)	Household agents calculate this parameter	favourite_HC E {0, 1} favourite_LC E {0, 1} Assessing based on the water bill of the effect of past water saving behaviour favouring high or low conservation

Social network links' variables

Variable	**Setup of parameter**	**Brief description**
impact_friend (>=0)	Household agents' links calculate this parameter	The force exerted to one household agent by the household agents that create its social network
social-distance (>=0)	Household agents' links calculate this parameter	The social distance between two household agents calculated based on the socio-economic characteristics: age, income and education of the household agents

Annex II – Online survey questionnaire

ΣΥΝΗΘΕΙΕΣ ΚΑΤΑΝΑΛΩΣΗΣ ΚΑΙ ΕΞΟΙΚΟΝΟΜΗΣΗΣ ΝΕΡΟΥ ΣΤΟ ΣΠΙΤΙ

1. Περιβαλλοντική Συνείδηση

1. Θεωρείτε ότι είστε:
Πολύ ευαισθητοποιημένος περιβαλλοντικά
Μέτρια ευαισθητοποιημένος περιβαλλοντικά
Λίγο ευαισθητοποιημένος περιβαλλοντικά
Καθόλου ευαισθητοποιημένος περιβαλλοντικά

2. Μιλώντας γενικά, για τα θέματα του περιβάλλοντος, πόσο ενημερωμένος/η θα λέγατε ότι είστε;
Πολύ ενημερωμένος/η
Αρκετά ενημερωμένος/η
Όχι και τόσο ενημερωμένος/η
Καθόλου ενημερωμένος/η;

3. Σε τι βαθμό ανησυχείτε για την κατάσταση του περιβάλλοντος; 1 (καθόλου) - 10 (πάρα πολύ)

4. Συμφωνείτε ή διαφωνείτε ότι:
Συμφωνώ απόλυτα (5) Ήπια Συμφωνώ (4) Αβέβαιος (3) Ήπια διαφωνώ (2) και Διαφωνώ (1)

- Πλησιάζουμε το όριο του αριθμού των ανθρώπων που η Γη μπορεί να αντέξει
- Οι άνθρωποι έχουν το δικαίωμα να μεταβάλουν το φυσικό περιβάλλον για να ακολουθεί τις ανάγκες τους
- Όταν οι άνθρωποι παρεμβαίνουν στη φύση αυτό συχνά έχει καταστροφικές συνέπειες
- Η ανθρώπινη εφευρετικότητα θα διασφαλίσει ότι η Γη δεν θα γίνει ακατάλληλη για κατοίκηση
- Οι άνθρωποι καταχράζονται το περιβάλλον
- Η Γη έχει αφθονία φυσικών πόρων και αρκεί να μάθουμε πώς να τα εκμεταλλευόμαστε
- Τα φυτά και τα ζώα έχουν τα ίδια δικαιώματα με τους ανθρώπους
- Η ισορροπία της φύσης είναι αρκετά ισχυρή για να αντιμετωπίσει τις επιπτώσεις των σύγχρονων βιομηχανικών εθνών
- Παρά τις ειδικές μας ικανότητες, οι άνθρωποι εξακολουθούν να υπόκεινται στους νόμους της φύσης
- Η λεγόμενη «οικολογική κρίση» που αντιμετωπίζει η ανθρωπότητα είναι σε μεγάλο βαθμό υπερβολική
- Η γη είναι σαν ένα διαστημόπλοιο με πολύ περιορισμένο χώρο και πόρους

- Οι άνθρωποι είναι γραφτό να κυριαρχήσουν της φύσης
- Η ισορροπία της φύσης είναι πολύ λεπτή και εύκολα αναστατώνεται
- Οι άνθρωποι τελικά θα μάθουν αρκετά για το πώς η φύση λειτουργεί και θα μπορέσουν να την ελέγχουν
- Αν τα πράγματα συνεχίσουν τη σημερινή πορεία τους , θα αντιμετωπίσουμε σύντομα μια μεγάλη οικολογική καταστροφή

2. Στάσεις απέναντι στην κατανάλωση οικιακού νερού

5. Συμφωνείτε ή διαφωνείτε:
Συμφωνώ απόλυτα (5) Ήπια Συμφωνώ (4) Αβέβαιος (3) Ήπια διαφωνώ (2) και Διαφωνώ (1)

- Δεν αισθάνομαι ότι πρέπει να κάνω εγώ οικονομία στο νερό εάν ο υπόλοιπος κόσμος κάνει κατάχρηση
- Θα κάνω οικονομία στο νερό μόνο αν μου επιβληθεί με κανονισμό
- Οι αγρότες έχουν μεγαλύτερο αντίκτυπο στους υδατικούς πόρους απ’ ότι οι οικιακοί χρήστες νερού
- Είμαι διατεθειμένος/η να ξοδέψω επιπλέον χρήματα προκειμένου να αποκτήσω συσκευές εξοικονόμησης νερού
- Προσέχω την κατανάλωση νερού που κάνω μόνο όταν βοηθά στο να μειώσω το κόστος του λογαριασμού του νερού
- Νοικοκυριά σαν το δικό μου δεν θα έπρεπε να κατηγορούνται για τα περιβαλλοντικά προβλήματα που προκαλούνται από τη ζήτηση πόσιμου νερού
- Η χρήση εναλλακτικών πηγών νερού (όπως το αφαλατωμένο και ποιοτικά αποκατεστημένο νερό) είναι ο καλύτερος τρόπος να καταπολεμηθεί η έλλειψη νερού
- Η εξοικονόμηση νερού είναι απαραίτητη λόγω της λειψυδρίας
- Θα μειώσω την κατανάλωση μου μόνο εάν το κάνουν και οι γείτονες μου
- Θα μειώσω την κατανάλωση μου μόνο αν μου επιβληθεί
- Χρησιμοποιώ τη σωστή ποσότητα νερού επειδή ο λογαριασμός νερού είναι χαμηλός
- Το νερό είναι πιο σημαντικό για μένα από ότι για τους γείτονες μου
- Μπορώ να χρησιμοποιώ όσο νερό θέλω από την ιδιωτική μου γεώτρηση
- Η δαπάνη για συσκευές εξοικονόμησης νερού δεν είναι μια έξυπνη επένδυση
- Η λειψυδρία έχει δημιουργηθεί εξαιτίας της υπερεκμετάλλευσης των πόρων από όλους τους άλλους

3. Λεπτομέρειες λογαριασμού οικιακής χρήσης νερού

6. Ποια η περίοδος χρέωσης του λογαριασμού σας;
Μηνιαία
Διμηνιαία
Κάθε τρεις μήνες
Κάθε τέσσερις μήνες
Κάθε έξι μήνες
Ετήσια
ΔΓ/ΔΑ

7. Πόση είναι περίπου η κατανάλωση νερού ανά λογαριασμό που κάνετε σε κυβικά μέτρα (κ.μ.) σύμφωνα με τους λογαριασμούς νερού που σας έρχονται;
0 – 10 κ.μ.
11 – 20 κ.μ.
21 – 40 κ.μ.

41 – 80 κ.μ.
81 – 120 κ.μ.
121 – 160 κ.μ.
161 – 200 κ.μ.
201 – 250 κ.μ.
251 – 300 κ.μ.
Πάνω από 300 κ.μ.
ΔΓ/ΔΑ

8. Και πόσα χρήματα πληρώνετε για το νερό ανά λογαριασμό σε ευρώ (€), σύμφωνα με τους λογαριασμούς νερού που σας έρχονται;
0 – 20 €
21 – 40 €
41 – 60 €
61 – 80 €
81 – 100 €
101 – 120 €
121 – 140 €
141 – 160 €
161 – 180 €
181 – 200 €
201 – 250 €
251 – 300 €
Πάνω από 300 €
ΔΓ/ΔΑ

4. Λεπτομέρειες εξοπλισμού οικιακής χρήσης νερού

9. Ποιές από τις παρακάτω συσκευές διαθέτει το νοικοκυριό σας;
Καζανάκι συμβατικό
Καζανάκι διπλής ροής
Καζανάκι χαμηλής ροής
Ντους χαμηλής ροής
Ηλεκτρικό ντους
Καμπίνα ντους
Συμβατικό ντους
Μπανιέρα spa
Μεγάλη μπανιέρα
Μεσαία μπανιέρα
Μικρή μπανιέρα
Χρησιμοποιώ την μπανιέρα σαν ντους
Νιπτήρα συμβατικό
Νιπτήρα με βρύση αερισμού
Νιπτήρα με βρύση ηλεκτρονική
Πλυντήριο ρούχων συμβατικό
Πλυντήριο ρούχων εξοικονόμησης νερού
Νεροχύτη συμβατικό
Νεροχύτη με βρύση αερισμού
Πλυντήριο πιάτων συμβατικό
Πλυντήριο πιάτων εξοικονόμησης νερού
Μπαλκόνι με ιθαγενή φυτά

Μπαλκόνι με ξυροθερμικά φυτά
Μπαλκόνι με φυτά χαμηλής κατανάλωσης νερού
Μπαλκόνι με φυτά (γενικά)
Κήπο με λαχανικά
Κήπο με γρασίδι
Κήπο με ιθαγενή φυτά
Κήπο με ξυροθερμικά φυτά
Κήπο με φυτά χαμηλής κατανάλωσης νερού
Κήπο με φυτά (γενικά)
Πισίνα
Τζακούζι
Σιντριβάνι
Άλλο (διευκρινίστε)

5. Λεπτομέρειες χρήσης εξοπλισμού οικιακής χρήσης νερού και εξοικονόμησης

10. Πόσο συχνά χρησιμοποιείτε τις παρακάτω συσκευές οικιακής χρήσης νερού;
(Παρακαλώ επιλέξτε τον αριθμό που θεωρείτε ότι χρησιμοποιείτε την κάθε συσκευή οικιακής χρήσης νερού. Εάν δεν χρησιμοποιείτε τη συσκευή καθημερινά τότε επιλέξτε από την εβδομαδιαία ή μηνιαία συχνότητα.)

Ημερήσια συχνότητα χρήσης Εβδομαδιαία συχνότητα χρήσης Μηνιαία συχνότητα χρήσης
Καζανάκι
Ντους
Μπανιέρα
Νιπτήρας
Πλυντήριο ρούχων
Νεροχύτης
Πλυντήριο πιάτων
Λάστιχο για πότισμα φυτών μπαλκονιού
Ποτιστήρι για πότισμα φυτών μπαλκονιού
Λάστιχο για πλύσιμο μπαλκονιού
Αυτόματο πότισμα κήπου
Λάστιχο για πότισμα κήπου
Λάστιχο για πλύσιμο αυτοκινήτου
Κουβά για πλύσιμο αυτοκινήτου
Πισίνα (γέμισμα)
Τζακούζι (γέμισμα)
Σιντριβάνι (γέμισμα)

11. Εάν θέλατε να κάνετε μικρή εξοικονόμηση νερού πόσο θα χρησιμοποιούσατε κάποιες από τις παρακάτω συσκευές οικιακής χρήσης νερού;
(Παρακαλώ επιλέξτε τη συχνότητα που θεωρείτε ότι θα χρησιμοποιούσατε κάποιες από τις παρακάτω συσκευές στην περίπτωση που θα θέλατε να κάνετε μικρή εξοικονόμηση νερού.)
Ημερήσια συχνότητα χρήσης Εβδομαδιαία συχνότητα χρήσης Μηνιαία συχνότητα χρήσης
Καζανάκι
Ντους
Μπανιέρα
Νιπτήρας
Πλυντήριο ρούχων
Νεροχύτης

Πλυντήριο πιάτων
Λάστιχο για πότισμα φυτών μπαλκονιού
Ποτιστήρι για πότισμα φυτών μπαλκονιού
Λάστιχο για πλύσιμο μπαλκονιού
Αυτόματο πότισμα κήπου
Λάστιχο για πότισμα κήπου
Λάστιχο για πλύσιμο αυτοκινήτου
Κουβά για πλύσιμο αυτοκινήτου
Πισίνα (γέμισμα)
Τζακούζι (γέμισμα)
Σιντριβάνι (γέμισμα)

12. Εάν θέλατε να κάνετε μεγάλη εξοικονόμηση νερού πόσο θα χρησιμοποιούσατε κάποιες από τις παρακάτω συσκευές οικιακής χρήσης νερού;
(Παρακαλώ επιλέξτε τη συχνότητα που θεωρείτε ότι θα χρησιμοποιούσατε κάποιες από τις παρακάτω συσκευές στην περίπτωση που θα θέλατε να κάνετε μεγάλη εξοικονόμηση νερού.)
Ημερήσια συχνότητα χρήσης Εβδομαδιαία συχνότητα χρήσης Μηνιαία συχνότητα χρήσης
Καζανάκι
Ντους
Μπανιέρα
Νιπτήρας
Πλυντήριο ρούχων
Νεροχύτης
Πλυντήριο πιάτων
Λάστιχο για πότισμα φυτών μπαλκονιού
Ποτιστήρι για πότισμα φυτών μπαλκονιού
Λάστιχο για πλύσιμο μπαλκονιού
Αυτόματο πότισμα κήπου
Λάστιχο για πότισμα κήπου
Λάστιχο για πλύσιμο αυτοκινήτου
Κουβά για πλύσιμο αυτοκινήτου
Πισίνα (γέμισμα)
Τζακούζι (γέμισμα)
Σιντριβάνι (γέμισμα)

13. Πέραν της μείωσης της συχνότητας χρήσης του εξοπλισμού οικιακής χρήσης νερού, τι άλλο θα ήσασταν διατεθειμένος να εφαρμόσετε ή εφαρμόζετε ήδη, για να εξοικονομήσετε νερό;
(Εφαρμόζω ήδη Θα ήθελα να εφαρμόσω Εξαρτάται από το κόστος Μου φαίνεται πολύ δύσκολο να το εφαρμόσω ΔΓ/ΔΑ)
Μείωση του χρόνου ντους.
Σιγουρεύομαι ότι οι βρύσες δεν στάζουν
Κλείνω τη βρύση όταν σαπουνίζομαι
Κλείνω τη βρύση όταν βουρτσίζω τα δόντια μου / πλένω τα χέρια μου

Κλείνω τη βρύση όταν πλένω τα πιάτα
Επαναχρησιμοποίηση νερού (από το νιπτήρα για την τουαλέτα κλπ) χωρίς εγκατάσταση εξοπλισμού.
Τοποθέτηση τούβλου στο καζανάκι για μείωση της χωρητικότητας του.
Έλεγχος για διαρροές και επισκευή τους από ειδικό.

Τοποθέτηση συστήματος συλλογής βρόχινου νερού.
Τοποθέτηση συστήματος ανακύκλωσης γκρι νερού.

6. Παράγοντες επιρροής για θέματα εξοικονόμησης οικιακής χρήσης νερού

14. Επιλέξτε το βαθμό επιρροής σας από τους παρακάτω παράγοντες σε θέματα εξοικονόμησης νερού οικιακής χρήσης.
Επηρεάζομαι απόλυτα (5) Επηρεάζομαι λίγο (4) Αβέβαιος (3) Δεν επηρεάζομαι ιδιαίτερα (2) και Δεν επηρεάζομαι καθόλου (1)
Οικογένεια
Φίλους
Γείτονες
Συναδέλφους
Υδραυλικούς
Δημοσιογράφους
Ειδικούς/επιστήμονες
Οικολογικές οργανώσεις
Εγχώρια μέσα μαζικής ενημέρωσης
Ξένα μέσα μαζικής ενημέρωσης
Μέσα κοινωνικής δικτύωσης
Blogs και forums

7. Δημογραφικά χαρακτηριστικά

15. Δημογραφικά χαρακτηριστικά
Φύλο
Ηλικία
Οικογενειακή Κατάσταση
Αριθμός μελών νοικοκυριού
Τύπος Κατοικίας
Κατοικία
Εκπαίδευση
Οικογενειακό εισόδημα (μηνιαίο)
Επάγγελμα
Προσωπικά στοιχεία

Annex III – Phone survey questionnaire

LIBRARY QUESTIONNAIRE YDROPOLIS

ΚΑΤΑΛΛΗΛΟΙ ΝΑ ΑΠΑΝΤΗΣΟΥΝ ΕΙΝΑΙ ΑΝΔΡΕΣ ΚΑΙ ΓΥΝΑΙΚΕΣ 18 ΕΤΩΝ ΚΑΙ ΑΝΩ ΥΠΕΥΘΥΝΟΙ ΓΙΑ ΤΟ ΝΟΙΚΟΚΥΡΙΟ (ΠΡΕΠΕΙ ΝΑ ΕΧΟΥΝ ΓΕΝΝΗΘΕΙ ΑΠΟ ΤΟ 1994 ΚΑΙ ΠΡΙΝ)

Κατ' αρχήν μπορείτε να μου πείτε σε ποιο Δήμο / Κοινότητα κατοικείτε ;

Με τι από τα παρακάτω που θα σας διαβάσω αισθάνεστε περισσότερο ταυτισμένος/η (δεμένος συναισθηματικά); (ΔΙΑΒΑΣΤΕ – ΜΕΧΡΙ ΔΥΟ ΑΠΑΝΤΗΣΕΙΣ)
Με την Ευρώπη 1
Με τον τόπο καταγωγής σας 2
Με την πόλη που κατοικείτε 3
Με τη γειτονιά/περιοχή που κατοικείτε 4
Με την Ελλάδα 5
Άλλο 6
ΔΓ/ΔΑ 9

ΠΕΡΙΒΑΛΛΟΝΤΙΚΕΣ ΣΤΑΣΕΙΣ & ΑΝΤΙΛΗΨΕΙΣ

Μιλώντας γενικά, για τα θέματα του περιβάλλοντος, πόσο ενημερωμένος/η θα λέγατε ότι είστε; Πολύ ενημερωμένος/η, αρκετά ενημερωμένος/η, όχι και τόσο ενημερωμένος/η, ή καθόλου ενημερωμένος/η;
Πολύ ενημερωμένος/η 1
Αρκετά ενημερωμένος/η 2
Όχι και τόσο ενημερωμένος/η 3
Καθόλου ενημερωμένος/η 4
ΔΓ/ΔΑ 9

Από τα περιβαλλοντικά προβλήματα που θα σας διαβάσω, ποια κατά τη γνώμη σας θα λέγατε ότι είναι τα σημαντικότερα; (ΔΙΑΒΑΣΤΕ – ΜΕΧΡΙ ΤΡΕΙΣ ΑΠΑΝΤΗΣΕΙΣ)
Μείωση των ενεργειακών πόρων 1
Έλλειψη νερού / Λειψυδρία 2
Αποψίλωση των δασών 3
Ερημοποίηση 4
Εξαφάνιση ειδών χλωρίδας και πανίδας 5
Συσσώρευση αποβλήτων 6
Ατμοσφαιρική ρύπανση 7
Αύξηση παγκόσμιου πληθυσμού 8

Εξάντληση φυσικών πόρων 9
Κλιματική αλλαγή 10
Άλλο (ποιο;__________) 11
ΔΓ/ΔΑ 99

Θα σας διαβάσω τώρα μερικές προτάσεις και θα ήθελα να μου πείτε για κάθε μία χωριστά αν συμφωνείτε (απόλυτα ή μάλλον) ή διαφωνείτε (απόλυτα ή μάλλον) με αυτές. (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΕΝΑ ΧΩΡΙΣΤΑ)

	Συμφωνώ απόλυτα	Μάλλον συμφωνώ	Ούτε συμφωνώ – ούτε διαφωνώ (ΑΥΘΟΡΜΗΤΑ)	Μάλλον διαφωνώ	Διαφωνώ απόλυτα	ΔΓ/ΔΑ
Οι άνθρωποι έχουν το δικαίωμα να μεταβάλλουν το φυσικό περιβάλλον ώστε να ανταποκρίνεται στις ανάγκες τους	1	2	3	4	5	9
Είναι υπερβολές τα όσα λέγονται για την «οικολογική κρίση» που αντιμετωπίζει η ανθρωπότητα	1	2	3	4	5	9

Τον τελευταίο χρόνο, πόσο συχνά θα λέγατε ότι κάνατε κάτι από τα παρακάτω στην καθημερινή σας ζωή; (ΔΙΑΒΑΣΤΕ) Θα λέγατε ότι το κάνατε πολύ συχνά, συχνά, μερικές φορές, σπάνια ή ποτέ;

	Πολύ Συχνά	Συχνά	Μερικές Φορές	Σπάνια	Ποτέ	ΔΓ/ΔΑ
Χρήση λαμπτήρων υψηλής απόδοσης	1	2	3	4	5	9
Χρήση ενεργειακά αποδοτικών συσκευών	1	2	3	4	5	9
Χρήση ανακυκλώσιμου χαρτιού αλληλογραφίας	1	2	3	4	5	9
Χρήση ανακυκλώσιμου χαρτιού τουαλέτας	1	2	3	4	5	9
Χρήση φυτών που χρειάζονται λιγότερο νερό	1	2	3	4	5	9

Διατήρηση της θερμοκρασίας θέρμανσης / θερμοστάτη σε χαμηλά επίπεδα για την εξοικονόμηση ενέργειας	1	2	3	4	5	9
Ανακύκλωση (γυαλιού, εφημερίδων, αλουμινένιων συσκευασιών αναψυκτικών, πλαστικών μπουκαλιών)	1	2	3	4	5	9

Θα σας διαβάσω τώρα μερικές προτάσεις και θα ήθελα να μου πείτε για κάθε μία χωριστά αν συμφωνείτε (απόλυτα ή μάλλον) ή διαφωνείτε (απόλυτα ή μάλλον) με αυτές. (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΕΝΑ ΧΩΡΙΣΤΑ)

	Συμφωνώ απόλυτα	Μάλλον συμφωνώ	Ούτε συμφωνώ – ούτε διαφωνώ (ΑΥΘΟΡΜΗΤΑ)	Μάλλον διαφωνώ	Διαφωνώ απόλυτα	ΔΓ/ΔΑ
Προσέχω την κατανάλωση νερού που κάνω μόνο όταν βοηθά στο να μειώσω το κόστος του λογαριασμού του νερού	1	2	3	4	5	9
Νοικοκυριά σαν το δικό μου δεν θα έπρεπε να κατηγορούνται για τα περιβαλλοντικά προβλήματα που προκαλούνται από τη ζήτηση για νερό	1	2	3	4	5	9
Η χρήση εναλλακτικών πηγών νερού (όπως το αφαλατωμένο και ποιοτικά αποκατεστημένο νερό) είναι ο καλύτερος τρόπος να καταπολεμηθεί η έλλειψη νερού	1	2	3	4	5	9

ΧΡΗΣΗ ΝΕΡΟΥ, ΑΝΤΙΛΗΨΕΙΣ ΚΑΙ ΣΤΑΣΕΙΣ

Α) Πληροφορίες λογαριασμού

Ποια η περίοδος χρέωσης του λογαριασμού σας; (ΔΙΑΒΑΣΤΕ)
Μηνιαία 1
Διμηνιαία 2
Κάθε τρεις μήνες 3
Κάθε τέσσερις μήνες 4
Κάθε έξι μήνες 5
Ετήσια 6
ΔΓ/ΔΑ 9

Πόση είναι περίπου η κατανάλωση νερού ανά λογαριασμό που κάνετε σε κυβικά μέτρα (m3) σύμφωνα με τους λογαριασμούς νερού που σας έρχονται;
0 – 10 m3 1
11 – 20 m3 2
21 – 40 m3 3
41 – 80 m3 4
81 – 120 m3 5
121 – 160 m3 6
161 – 200 m3 7
201 – 250 m3 8
251 – 300 m3 9
Πάνω από 300 m3 10
ΔΓ/ΔΑ 99

Και πόσα χρήματα πληρώνετε για το νερό ανά λογαριασμό σε ευρώ (€), σύμφωνα με τους λογαριασμούς νερού που σας έρχονται;
0 – 20 € 1
21 – 40 € 2
41 – 60 € 3
61 – 80 € 4
81 – 100 € 5
101 – 120 € 6
121 – 140 € 7
141 – 160 € 8
161 – 180 € 9
181 – 200 € 10
201 – 250 € 11
251 – 300 € 12
Πάνω από 300 € 13
ΔΓ/ΔΑ 99

β) Υποδομή και συσκευές νερού οικιακής χρήσης

Έχετε πλυντήριο ρούχων στο νοικοκυριό; (ΕΑΝ ΝΑΙ) Πότε αγοράστηκε το πλυντήριο ρούχων που έχετε στο νοικοκυριό;
Πριν από το 1990 1
1991 - 2000 2
2000 - 2010 3

2011 και μετά 4
Δεν έχω πλυντήριο ρούχων 5 => ΠΗΓΑΙΝΕ ΕΡ.24
ΔΓ/ΔΑ 9

Σε τι κατηγορία ενεργειακής κλάσης ανήκει το πλυντήριο ρούχων που έχετε στο νοικοκυριό; (ΔΙΑΒΑΣΤΕ)
A (Αποδοτικό) 1
B 2
C 3
D 4
E 5
F 6
G (Μη αποδοτικό) 7
ΔΓ/ΔΑ 9

Σε τι θερμοκρασία πλένετε συνήθως στο πλυντήριο ρούχων που έχετε στο νοικοκυριό; (ΔΙΑΒΑΣΤΕ)
Κάτων από 30 βαθμούς 1
31 έως 40 βαθμούς 2
41 έως 60 βαθμούς 3
61 έως 80 βαθμούς 4
80 έως 90 βαθμούς 5
Πάνω από 90 βαθμούς 6
ΔΓ/ΔΑ 9

Κατά μέσο όρο, πόσο συχνά χρησιμοποιείτε το πλυντήριο ρούχων μέσα στην εβδομάδα; (ΔΙΑΒΑΣΤΕ)
6-7 μέρες την εβδομάδα 1
4-5 μέρες την εβδομάδα 2
2-3 μέρες την εβδομάδα 3
1 μέρα την εβδομάδα 4
Σπανιότερα 5
ΔΓ/ΔΑ 9

Έχετε πλυντήριο πιάτων στο νοικοκυριό; (ΕΑΝ ΝΑΙ) Πότε αγοράστηκε το πλυντήριο πιάτων που έχετε στο νοικοκυριό;
Πριν από το 1990 1
1991 - 2000 2
2000 - 2010 3
2011 και μετά 4
Δεν έχω πλυντήριο πιάτων 5 => ΠΗΓΑΙΝΕ ΕΡ.27
ΔΓ/ΔΑ 9

Σε τι κατηγορία ενεργειακής κλάσης ανήκει το πλυντήριο πιάτων που έχετε στο νοικοκυριό; (ΔΙΑΒΑΣΤΕ)
A (Αποδοτικό) 1
B 2
C 3
D 4
E 5
F 6

G (Μη αποδοτικό) 7
ΔΓ/ΔΑ 9

Κατά μέσο όρο, πόσο συχνά χρησιμοποιείτε το πλυντήριο πιάτων μέσα στην εβδομάδα; (ΔΙΑΒΑΣΤΕ)
6-7 μέρες την εβδομάδα 1
4-5 μέρες την εβδομάδα 2
2-3 μέρες την εβδομάδα 3
1 μέρα την εβδομάδα 4
Σπανιότερα 5
ΔΓ/ΔΑ 9

Έχετε ντους στο νοικοκυριό; (ΕΑΝ ΝΑΙ) Πότε κατασκευάστηκε το ντους που έχετε στο νοικοκυριό;
Πριν από το 1980 1
1981 - 1990 2
1991 - 2000 3
2001 και μετά 4
Δεν έχω ντους 5 => ΠΗΓΑΙΝΕ ΕΡ.35
ΔΓ/ΔΑ 9

Τι τύπο ντους διαθέτει το νοικοκυριό; (ΔΙΑΒΑΣΤΕ)
Ντους χαμηλής ροής 1
Ηλεκτρικό ντους 2
Καμπίνα ντους 3
Συμβατικό ντους 4
ΔΓ/ΔΑ 9

Ποια είναι η μέση διάρκεια ενός ντους σας;	ΩΡΕΣ	ΛΕΠΤΑ	ΔΘ	88	ΔΑ	99

Σε γενικές γραμμές, όταν κάνετε ντους, προτιμάτε το νερό να είναι… (ΔΙΑΒΑΣΤΕ)
Κρύο 1
Δροσερό 2
Χλιαρό 3
Ζεστό 4
Καυτό 5
ΔΓ/ΔΑ 9

Πόσο συχνά θα λέγατε ότι κάνετε ντους μέσα στην μέσα στην εβδομάδα κατά τους χειμερινούς μήνες; (ΔΙΑΒΑΣΤΕ)
Περισσότερο από μία φορά την ημέρα 1
1 φορά τη μέρα 1
2 με 3 φορές τη βδομάδα 2
1 φορά την εβδομάδα 3
Σπανιότερα 5
ΔΓ/ΔΑ 9

Και πόσο συχνά θα λέγατε ότι κάνετε ντους μέσα στην μέσα στην εβδομάδα κατά τους καλοκαιρινούς μήνες; (ΔΙΑΒΑΣΤΕ)

Περισσότερο από μία φορά την ημέρα 1
1 φορά τη μέρα 1
2 με 3 φορές τη βδομάδα 2
1 φορά την εβδομάδα 3
Σπανιότερα 5
ΔΓ/ΔΑ 9

Κατά μέσο όρο πόσα ντους γίνονται στο νοικοκυριό από όλα τα μέλη του (μαζί με εσάς);			ΔΘ	88	ΔΑ	99

Γενικά, θα λέγατε ότι κάνετε κάποια προσπάθεια να μειώσετε τον αριθμό των ντους που κάνετε μέσα στη βδομάδα;

Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

Έχετε μπανιέρα στο νοικοκυριό; (ΕΑΝ ΝΑΙ) Τι τύπο μπανιέρας διαθέτει το νοικοκυριό; (ΔΙΑΒΑΖΩ)
Υδρομασάζ (SPA - σπα) 1
Μεγάλη μπανιέρα 2
Μεσαία μπανιέρα 3
Μικρή μπανιέρα 4
Walk-in μπανιέρα 5
Δεν έχω μπανιέρα 6 => ΠΗΓΑΙΝΕ ΕΡ.40
ΔΓ/ΔΑ 9

Γεμίζετε τη μπανιέρα όταν κάνετε μπάνιο; (ΕΑΝ ΝΑΙ) Συνήθως τη γεμίζετε…(ΔΙΑΒΑΣΤΕ)
Ολόκληρη 1
Τα ¾ (τρία τέταρτα) 2
Το ½ (ένα δεύτερο) – τη μισή 3
Το ¼ (ένα τέταρτο) 4
Όχι, δεν τη γεμίζω 5
ΔΓ/ΔΑ 9

Κατά μέσο όρο πόσα μπάνια γίνονται στο νοικοκυριό από όλα τα μέλη του (μαζί με εσάς) μέσα στη βδομάδα;			ΔΘ	88	ΔΑ	99

Σε γενικές γραμμές, προτιμάτε / επιδιώκετε να κάνετε μπάνιο ή ντους; (ΔΙΑΒΑΣΤΕ)
Μπάνιο 1
Ντους 2
Δεν έχω προτίμηση (ΑΥΘΟΡΜΗΤΑ) 3
ΔΓ/ΔΑ 9

Γενικά, θα λέγατε ότι κάνετε κάποια προσπάθεια να μειώσετε τον αριθμό των μπάνιων που κάνετε μέσα στη βδομάδα;
Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

Πόσο συχνά θα λέγατε ότι κάνετε κάτι από τα παρακάτω στην καθημερινή σας ζωή; (ΔΙΑΒΑΣΤΕ) Θα λέγατε ότι το κάνετε πολύ συχνά, συχνά, μερικές φορές, σπάνια ή ποτέ;

	Πολύ Συχνά	Συχνά	Μερικές Φορές	Σπάνια	Ποτέ	Δεν με αφορά (ΑΥΘΟΡΜΗΤΑ)	ΔΓ/ΔΑ
Σιγουρεύομαι ότι οι βρύσες δεν στάζουν	1	2	3	4	5	8	9
Κλείνω τη βρύση όταν σαπουνίζομαι	1	2	3	4	5	8	9
Κλείνω τη βρύση όταν βουρτσίζω τα δόντια μου / πλένω τα χέρια μου	1	2	3	4	5	8	9
Κλείνω τη βρύση όταν πλένω τα πιάτα	1	2	3	4	5	8	9

Ποιο από τα παρά κάτω συστήματα θέρμανσης νερού διαθέτετε στο νοικοκυριό σας; (ΔΙΑΒΑΣΤΕ – ΜΙΑ ΑΠΑΝΤΗΣΗ)
Ηλεκτρικός θερμοσίφωνας (ηλεκτρομπόιλερ) 1
Ηλιακός θερμοσίφωνας 2
Μπόιλερ λεβητοστασίου 3
Άλλο (τι;____________)4
ΔΓ/ΔΑ 9

Τι από τα παρακάτω διαθέτει το νοικοκυριό σας; (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΕΝΑ ΧΩΡΙΣΤΑ)

	ΝΑΙ	ΟΧΙ	ΔΓ/ΔΑ
Διακοσμητικό συντριβάνι	1	2	9
Spa – Τζακούζι	1	2	9
Κήπο με φρούτα και λαχανικά	1	2	9
Κήπο με γρασίδι	1	2	9
Μπαλκόνι με φυτά	1	2	9
Μεγάλη πισίνα	1	2	9

Σε γενικές γραμμές, υπάρχουν τα παρακάτω είδη φυτών στο νοικοκυριό σας ;

	Υπάρχουν	Δεν υπάρχουν	ΔΓ/ΔΑ
Ιθαγενή (της περιοχής σας)	1	2	9
Ξηροθερμικά	1	2	9
Χαμηλής κατανάλωσης νερού	1	2	9

Στο νοικοκυριό σας διαθέτετε κάποιο είδος εξοπλισμού για πότισμα; (ΕΑΝ ΝΑΙ) Τι τύπο εξοπλισμού διαθέτετε; (ΠΟΛΛΑΠΛΕΣ ΑΠΑΝΤΗΣΕΙΣ ΔΥΝΑΤΕΣ)

Απλό λάστιχο νερού 1
Λάστιχο με πιστόλι εκτόξευσης νερού 2
Ποτιστικό κήπου / αυτόματο πότισμα 3
Σύστημα άρδευσης με αισθητήρα βροχής 4
Άλλο (τι;_________________________) 5
ΔΓ/ΔΑ 9

Πόσο συχνά θα λέγατε ότι ποτίζετε τα φυτά σας μέσα στην εβδομάδα; (Όχι καλοκαιρινούς μήνες) (ΔΙΑΒΑΣΤΕ)

Περισσότερο από μία φορά την ημέρα 1
1 φορά τη μέρα 1
2 με 3 φορές τη βδομάδα 2
1 φορά την εβδομάδα 3
Σπανιότερα 5
ΔΓ/ΔΑ 9

Και ειδικότερα, πόσο συχνά θα λέγατε ότι ποτίζετε τα φυτά σας μέσα στην εβδομάδα κατά τους καλοκαιρινούς μήνες; (ΔΙΑΒΑΣΤΕ)

Περισσότερο από μία φορά την ημέρα 1
1 φορά τη μέρα 1
2 με 3 φορές τη βδομάδα 2
1 φορά την εβδομάδα 3
Σπανιότερα 5
ΔΓ/ΔΑ 9

Στο νοικοκυριό υπάρχει αυτοκίνητο ή μοτοσικλέτα / παπί / σκούτερ;

Ναι 1 => ΠΗΓΑΙΝΕ ΕΡ.58
Όχι 2 => ΠΗΓΑΙΝΕ ΕΡ.60
ΔΓ/ΔΑ 9 => ΠΗΓΑΙΝΕ ΕΡ.60

Πόσο συχνά θα λέγατε ότι πλένετε το όχημα σας στο σπίτι; (ΔΙΑΒΑΣΤΕ)

Σχεδόν κάθε μέρα 1
2-3 φορές την εβδομάδα 2
1 φορά την εβδομάδα 3
2-3 φορές το μήνα 4
1 φορά το μήνα 5
1 φορά το δίμηνο 6
Πιο σπάνια 7
Ποτέ 8 => ΠΗΓΑΙΝΕ ΕΡ.60
ΔΓ/ΔΑ 9 => ΠΗΓΑΙΝΕ ΕΡ.60

Τι σύστημα ποτίσματος χρησιμοποιείτε για να πλύνετε το όχημα στο σπίτι σας ;(ΔΙΑΒΑΣΤΕ)

Απλό λάστιχο νερού 1
Λάστιχο με πιστόλι εκτόξευσης νερού 2
Κουβά με νερό 3
Πιεστικό 4
Άλλο (τι;_______________) 5
ΔΓ/ΔΑ 9

Υπάρχει τοπικό σύστημα ανακύκλωσης νερού στο σπίτι / στην πολυκατοικία / στη γειτονιά σας;

Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

Υπάρχει τοπικό σύστημα συλλογής βρόχινου νερού στο σπίτι / στην πολυκατοικία / στη γειτονιά σας;

Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

ΓΕΝΙΚΕΣ ΣΤΑΣΕΙΣ ΑΠΕΝΑΝΤΙ ΣΤΗΝ ΚΑΤΑΝΑΛΩΣΗ ΝΕΡΟΥ

Συχνά λέγεται ότι ένα από τα οφέλη της χρήσης εναλλακτικών πηγών νερού (δημόσια επεξεργασμένα αστικά λύματα, δημόσια αφαλάτωση, ανακυκλωμένο νερό από ιδιωτική χρήση – εκτός λυμάτων τουαλέτας - , ιδιωτική συλλογή βρόχινου νερού) είναι η εξοικονόμηση νερού. Κατά τη γνώμη σας ένα τέτοιο όφελος πόσο σημαντικό θα λέγατε ότι είναι; (ΔΙΑΒΑΣΤΕ)

Πολύ σημαντικό 1
Αρκετά σημαντικό 2
Όχι και τόσο σημαντικό 3
Καθόλου σημαντικό 4
ΔΓ/ΔΑ 9

Τον τελευταίο χρόνο, τους τελευταίους δώδεκα μήνες, πόσο θα λέγατε ότι προσπαθήσατε για να βρείτε πληροφορίες για θέματα που σχετίζονται με το νερό (π.χ. ανακύκλωση νερού, αφαλάτωση, εξοικονόμηση νερού, βρόχινο νερό, κ.λπ.); (ΔΙΑΒΑΣΤΕ)

Πολύ 1
Αρκετά 2
Λίγο 3
Καθόλου 4
ΔΓ/ΔΑ 9

Έχετε υποστεί ποτέ περιορισμούς στη χρήση του νερού;

Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

Σε σχέση με τους γείτονές σας, θα λέγατε ότι χρησιμοποιείτε περισσότερη, λιγότερη ή την ίδια περίπου ποσότητα νερού;

Περισσότερη 1
Λιγότερη 2
Την ίδια 3
Εξαρτάται (ΑΥΘΟΡΜΗΤΑ) 4
ΔΓ/ΔΑ 9

Πόσο θα λέγατε ότι συμφωνείτε ή διαφωνείτε με την παρακάτω πρόταση: «Είμαι διατεθειμένος/η να ξοδέψω επιπλέον χρήματα προκειμένου να αποκτήσω συσκευές

εξοικονόμησης νερού»; Θα λέγατε ότι συμφωνείτε απόλυτα, μάλλον συμφωνείτε, μάλλον διαφωνείτε ή διαφωνείτε απόλυτα;
Συμφωνώ απόλυτα 1
Μάλλον συμφωνώ 2
Μάλλον διαφωνώ 3
Διαφωνώ απόλυτα 4
ΔΓ/ΔΑ 9

Θα σας διαβάσω τώρα μερικές προτάσεις και θα ήθελα να μου πείτε για κάθε μία χωριστά αν συμφωνείτε (απόλυτα ή μάλλον) ή διαφωνείτε (απόλυτα ή μάλλον) με αυτές. (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΕΝΑ ΧΩΡΙΣΤΑ)

	Συμφωνώ απόλυτα	Μάλλον συμφωνώ	Ούτε συμφωνώ – ούτε διαφωνώ (ΑΥΘΟΡΜΗΤΑ)	Μάλλον διαφωνώ	Διαφωνώ απόλυτα	ΔΓ/ΔΑ
Δεν αισθάνομαι ότι πρέπει να κάνω εγώ οικονομία στο νερό εάν ο υπόλοιπος κόσμος κάνει κατάχρηση	1	2	3	4	5	9
Θα κάνω οικονομία στο νερό μόνο αν μου επιβληθεί με κανονισμό	1	2	3	4	5	9
Μπορώ να χρησιμοποιώ όσο νερό θέλω από το πηγάδι / τη γεώτρησή μου	1	2	3	4	5	9
Οι αγρότες έχουν μεγαλύτερο αντίκτυπο στους υδάτινους πόρους απ' ότι οι οικιακοί χρήστες νερού	1	2	3	4	5	9

ΣΤΑΣΕΙΣ ΑΠΕΝΑΝΤΙ ΣΤΗ ΧΡΗΣΗ ΕΝΑΛΛΑΚΤΙΚΩΝ ΠΗΓΩΝ ΝΕΡΟΥ

Έχει τύχει να ακούσετε ή να διαβάσετε κάτι σχετικά με την έννοια «Γκρι Νερό»;
Ναι 1 ➚ Πήγαινε Ερ. 72
Όχι 2 ➚ Πήγαινε Ερ. 73
ΔΓ/ΔΑ 9 ➚ Πήγαινε Ερ. 73

Θα ήθελα τώρα να μου πείτε αν γνωρίζετε τι είναι το, δηλαδή το «Γκρι Νερό» (ΑΥΘΟΡΜΗΤΑ)
Ναι, είναι το νερό που προέρχεται από τη χρήση του νεροχύτη, πλυντηρίου πιάτων, πλυντηρίου ρούχων, μπανιέρας & νιπτήρα μπάνιου το οποίο μπορεί να επεξεργαστεί και να ξαναχρησιμοποιηθεί για άλλες οικιακές χρήσεις (πχ πότισμα κήπου, γλαστρών, γέμισμα πισίνας) (ΣΩΣΤΗ ΑΠΑΝΤΗΣΗ) 1
Ναι, ... (ΛΑΘΟΣ ΑΠΑΝΤΗΣΗ) 2
Όχι, δεν γνωρίζω 8
ΔΑ 9

Το «Γκρι Νερό» είναι το νερό που προέρχεται από τη χρήση του νεροχύτη, πλυντηρίου πιάτων, πλυντηρίου ρούχων, μπανιέρας & νιπτήρα μπάνιου το οποίο μπορεί να επεξεργαστεί και να ξαναχρησιμοποιηθεί για άλλες οικιακές χρήσεις (π.χ. πότισμα κήπου, γλαστρών, γέμισμα πισίνας). Εσάς θα σας ενδιέφερε να χρησιμοποιήσετε αυτό το νερό για άλλες οικιακές χρήσεις στο νοικοκυριό σας;
Ναι 1
Όχι 2
Εξαρτάται το κόστος επεξεργασίας (ΑΥΘΟΡΜΗΤΑ) 3
ΔΓ/ΔΑ 9

Προκειμένου να αυξηθεί ο όγκος του νερού που είναι διαθέσιμος για οικιακή κατανάλωση στην Αττική, θα ήθελα να μου πείτε πόσο κατάλληλη θεωρείτε κάθε μία από τις παρακάτω εναλλακτικές πηγές νερού; (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΜΙΑ ΧΩΡΙΣΤΑ) Θα λέγατε ότι τη θεωρείτε απολύτως κατάλληλη, μάλλον κατάλληλη, μάλλον ακατάλληλη ή απολύτως ακατάλληλη;

	Απολύτως κατάλληλη	Μάλλον κατάλληλη	Μάλλον ακατάλληλη	Απολύτως ακατάλληλη	ΔΓ/ΔΑ
Νερό από δημόσια επεξεργασμένα αστικά λύματα	1	2	3	4	9
Νερό από δημόσια αφαλάτωση	1	2	3	4	9
Ανακυκλωμένο νερό από ιδιωτική χρήση (εκτός λυμάτων τουαλέτας)	1	2	3	4	9
Ιδιωτική συλλογή βρόχινου νερού	1	2	3	4	9

Έχετε χρησιμοποιήσει ποτέ νερό που προέρχεται από δημόσιο σύστημα επεξεργασίας αστικών λυμάτων, δημόσιο σύστημα αφαλάτωσης νερού, ιδιωτικό σύστημα ανακύκλωσης νερού ιδιωτικής χρήσης (εκτός λυμάτων τουαλέτας) ή ιδιωτικό σύστημα συλλογής βρόχινου νερού;
Ναι 1
Όχι 2
ΔΓ/ΔΑ 9

Κατά τη γνώμη σας, προκειμένου να τεθούν σε εφαρμογή τεχνολογίες συλλογής νερού από εναλλακτικές πηγές, ποια από τα παρακάτω κριτήρια πρέπει να ληφθούν κυρίως υπόψη; (ΔΙΑΒΑΣΤΕ - ΜΕΧΡΙ ΤΡΕΙΣ ΑΠΑΝΤΗΣΕΙΣ)

Το κόστος αγοράς του συστήματος 1
Το κόστος λειτουργίας και συντήρησης του συστήματος 2
Η ενδυνάμωση των τοπικών φορέων 3
Το επίπεδο δημόσιας αποδοχής του συστήματος 4
Οι κίνδυνοι για την υγεία 5
Η κατανάλωση ενέργειας (έκλυση διοξειδίου του άνθρακα – CO2) 6
Άλλες περιβαλλοντικές επιπτώσεις 7
Ο χρόνος της εφαρμογής 8
Η ενημέρωση για το θέμα 9
Άλλο (τι;____________________) 10
ΔΓ/ΔΑ 99

Φανταστείτε ότι ζείτε σε μια πόλη όπου υπάρχει περιορισμένη διαθεσιμότητα πόσιμου νερού, υπάρχουν υποχρεωτικοί περιορισμοί στη χρήση του νερού, ενώ υπάρχει άμεσα διαθέσιμο, χωρίς περιορισμούς, νερό από κάποια εναλλακτική πηγή (από δημόσιο σύστημα επεξεργασίας αστικών λυμάτων ή / και από δημόσιο σύστημα αφαλάτωσης νερού).
Εσείς προσωπικά, πόσο πιθανό θα λέγατε ότι θα χρησιμοποιούσατε το νερό αυτό για… (ΔΙΑΒΑΣΤΕ ΚΑΘΕ ΕΝΑ ΧΩΡΙΣΤΑ) Θα λέγατε ότι είναι πολύ πιθανό, αρκετά πιθανό, όχι και τόσο πιθανό ή καθόλου πιθανό;

	Πολύ πιθανό	Αρκετά πιθανό	Όχι και τόσο πιθανό	Καθόλου πιθανό	ΔΓ/ΔΑ
…να πλύνετε τα ρούχα / βάλετε πλυντήριο;	1	2	3	4	9
…να μαγειρέψετε;	1	2	3	4	9
…να κάνετε ντους / μπάνιο;	1	2	3	4	9
…να πιείτε νερό;	1	2	3	4	9
…να βουρτσίσετε στα δόντια σας;	1	2	3	4	9

Θα ήσασταν πρόθυμος/η να γίνεται ιδιοκτήτης ενός ιδιωτικού συστήματος ανακύκλωσης νερού ιδιωτικής χρήση (εκτός λυμάτων τουαλέτας) και υπεύθυνος για τη σωστή λειτουργία και συντήρησή του;
Ναι 1
Όχι 2
Εξαρτάται (ΑΥΘΟΡΜΗΤΑ) 3
ΔΓ/ΔΑ 9

Θα ήσασταν πρόθυμος/η να γίνεται ιδιοκτήτης ενός συστήματος ιδιωτικής συλλογής βρόχινου νερού και υπεύθυνος για τη σωστή λειτουργία και συντήρησή του;
Ναι 1
Όχι 2
Εξαρτάται (ΑΥΘΟΡΜΗΤΑ) 3
ΔΓ/ΔΑ 9

ΔΗΜΟΓΡΑΦΙΚΑ ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ ΕΡΩΤΩΜΕΝΟΥ
Θα ήθελα τώρα καθαρά για στατιστικούς λόγους να σας ζητήσω ορισμένα δημογραφικά στοιχεία:

Φύλο

Φύλο:	Άνδρας	1	Γυναίκα	2

Ηλικία

Γεννηθήκατε το 19..; / (Πότε γεννηθήκατε:)	1	9			ΔΘ	888	ΔΑ	999

Τι σπουδές έχετε τελειώσει/ συμπληρώσει;
[ΣΗΜΕΙΩΝΕΤΕ ΤΟΝ ΑΝΩΤΑΤΟ ΤΙΤΛΟ ΣΠΟΥΔΩΝ ΠΟΥ ΚΑΤΕΧΕΙ Ο ΕΡΩΤΩΜΕΝΟΣ/Η]

Δεν έχει πάει καθόλου σχολείο / δεν γνωρίζει γραφή και ανάγνωση	1
Έχει τελειώσει 1η, ή 2α Δημοτικού	2
Έχει τελειώσει 3η, 4η, ή 5η Δημοτικού	3
Έχει πάρει απολυτήριο Δημοτικού	4
Έχει τελειώσει 1η, ή 2α Γυμνασίου	5
Έχει πάρει απολυτήριο τριτάξιου Γυμνασίου	6
Έχει πτυχίο Τεχνικής – Επαγγελματικής Σχολής (ΤΕΣ), χωρίς απολυτήριο Λυκείου	7
Έχει τελειώσει 1η, ή 2α Λυκείου / 4η, ή 5η εξατάξιου Γυμνασίου	8
Έχει απολυτήριο Τεχνικού Επαγγελματικού Λυκείου (ΤΕΛ)	9
Έχει απολυτήριο Λυκείου (Γενικού, Ενιαίου Πολυκλαδικού) / Απολυτήριο εξατάξιου Γυμνασίου	10
Έχει πτυχίο Μεταδευτεροβάθμιας Εκπαίδευσης / Μέσης Ιδιωτικής Τεχνικής Επαγγελματικής Σχολής, με απολυτήριο Λυκείου (π.χ. ΙΕΚ, Ιδιωτικά Κολλέγια, Κέντρα Ελευθ. Σπουδών, κ.λπ).	11
Έχει πτυχίο ΤΕΙ / ΚΑΤΕ / ΚΑΤΕΕ	12
Έχει πτυχίο ΑΕΙ	13
Κάτοχος Μεταπτυχιακού τίτλου (Μάστερ, Διδακτορικό, κ.λπ.)	14
ΔΓ/ΔΑ	99

Σήμερα με τι ασχολείσθε; (Ποια είναι η επαγγελματική σας κατάσταση;)
(ΕΑΝ ΝΑΙ) ΕΡΓΑΖΕΣΤΕ και είστε Εργοδότης/επιχειρηματίας, Αυτοαπασχολούμενος, ή μισθωτός;
(ΕΑΝ ΑΥΤΟΑΠΑΣΧΟΛΟΥΜΕΝΟΣ) Είστε Αγρότης- κτηνοτρόφος-ψαράς, Ελεύθερος επαγγελματίας, Μικρέμπορος, Βιοτέχνης, Επαγγελματίας (π.χ. υδραυλικός, ηλεκτρολόγος, ιδιοκτήτης TAXI)

Εργοδότης / Επιχειρηματίας / Απασχολεί μισθωτούς υπαλλήλους από 5 άτομα και άνω	1
Αυτοαπασχολούμενος / Αγρότης, κτηνοτρόφος, ψαράς	2
Αυτοαπασχολούμενος / Ελεύθερος επαγγελματίας (π.χ. γιατρός, δικηγόρος, μηχανικός, αρχιτέκτονας, λογιστής, οικονομολόγος, σύμβουλος επιχείρησης, εκτελωνιστής)	3
Αυτοαπασχολούμενος / Μικρέμπορος, μικρό μαγαζί – μικρή βιοτεχνία, βιοτέχνης, επαγγελματίας (π.χ. υδραυλικός, ηλεκτρολόγος, ιδιοκτήτης TAXI)	4
(ΕΑΝ ΜΙΣΘΩΤΟΣ) Δημοσίου Τομέα	
Υψηλόβαθμο Στέλεχος / Διευθυντής	5
Μεσαίο Στέλεχος (Τμηματάρχης – Προϊστάμενος)	6
Κατώτερο Προσωπικό (Υπάλληλος Γραφείου)	7
Ειδικευμένος Εργάτης	8
Ανειδίκευτος Εργάτης / Κλητήρας / Καθαριστής/ρια	9
Εργαζόμενος part – time, συμβασιούχος	10
Άλλο	11

(ΕΑΝ ΜΙΣΘΩΤΟΣ) Ιδιωτικού Τομέα	
Υψηλόβαθμο Στέλεχος / Διευθυντής	12
Μεσαίο Στέλεχος / Πωλητής	13
Κατώτερο Προσωπικό (Υπάλληλος Γραφείου)	14
Ειδικευμένος Εργάτης / Επόπτης	15
Ανειδίκευτος Εργάτης / Κλητήρας / Καθαριστής/ρια	16
Εργαζόμενος part – time όπως delivery, courier, call center, ελαστικής απασχόλησης	17
Άλλο	18
ΑΝ ΔΕΝ ΕΡΓΑΖΕΣΤΕ είστε άνεργος, νοικοκυρά, συνταξιούχος, μαθητής-σπουδαστής-φοιτητής-φαντάρος, εισοδηματίας;	
(ΕΑΝ ΑΝΕΡΓΟΣ) Άνεργος/η που δεν έχει ξαναδουλέψει και ζητάει δουλειά για πρώτη φορά, ή άνεργος/η που έχει ξαναδουλέψει και τώρα είναι άνεργος/η;	
Άνεργος/η (που δεν έχει ξαναδουλέψει και ζητάει δουλειά για πρώτη φορά)	19
Άνεργος/η (που έχει ξαναδουλέψει και τώρα είναι άνεργος)	20
Νοικοκυρά	21
(ΕΑΝ ΣΥΝΤΑΞΙΟΥΧΟΣ) Είστε συνταξιούχος Δημοσίου, ή Ιδιωτικού Τομέα;	
Συνταξιούχος Δημοσίου Τομέα	22
Συνταξιούχος Ιδιωτικού Τομέα (π.χ. ΙΚΑ, ΟΓΑ, ΤΕΒΕ, ΤΣΑ, κ.λπ.)	23
Μαθητής / Σπουδαστής / Φοιτητής / Φαντάρος	24
Εισοδηματίας	25
Άλλο	26
ΔΑ	99

Ποια είναι η οικογενειακή σας κατάσταση; (ΔΙΑΒΑΣΤΕ)

Παντρεμένος/η 1
Ανύπαντρος/η που ζει με γονείς / συγγενείς 2
Ανύπαντρος/η που ζει μόνος/η, ή με συγκάτοικο 3
Χήρος/α 4
Διαζευγμένος/η / Σε διάσταση 5
ΔΑ 9

Από πόσα μέλη αποτελείται το νοικοκυριό σας;
(Μαζί με εσάς)

Έχετε παιδιά που μένουν μαζί σας; (ΕΑΝ ΝΑΙ) Πόσα παιδιά έχετε;

Ναι, 1 1
Ναι, 2 2
Ναι, 3 3
Ναι, 4 4
Ναι, 4+ 5
Όχι, δεν υπάρχουν παιδιά στο νοικοκυριό 6
ΔΑ 9

Το σπίτι στο οποίο μένετε είναι ιδιόκτητο ή με ενοίκιο;

Ιδιόκτητο 1
Με ενοίκιο 2
ΔΓ/ΔΑ 9

Πως θα περιγράφατε καλύτερα το σπίτι, στο οποίο μένετε; Μονοκατοικία, διόροφη μονοκατοικία, μεζονέτα, διπλοκατοικία, πολυκατοικία; (ΕΑΝ ΠΟΛΥΚΑΤΟΙΚΙΑ) Πόσους ορόφους έχει η πολυκατοικία που μένετε;

Μονοκατοικία 1
Διόροφη μονοκατοικία 2
Μεζονέτα 3
Διπλοκατοικία 4
Πολυκατοικία (3 όροφοι) 5
Πολυκατοικία (4 όροφοι) 6
Πολυκατοικία (5 όροφοι) 7
Πολυκατοικία (6 όροφοι) 8
Πολυκατοικία (7 όροφοι) 9
Πολυκατοικία (8 όροφοι) 10
Πολυκατοικία (9 όροφοι) 11
Πολυκατοικία (10 όροφοι) 12
Πολυκατοικία (11 όροφοι και άνω) 13
ΔΓ/ΔΑ 99

Περίπου πόσα τετραγωνικά μέτρα είναι το σπίτι στο οποίο κατοικείτε;

Δεν γνωρίζω 888
Δεν απαντώ 999

Έχετε κήπο στο σπίτι στο οποίο κατοικείτε; (ΕΑΝ ΝΑΙ) Περίπου πόσα τετραγωνικά μέτρα είναι ο κήπος του σπιτιού σας;

Όχι, δεν έχω κήπο 777
Δεν γνωρίζω 888
Δεν απαντώ 999

Έχετε μπαλκόνια στο σπίτι στο οποίο κατοικείτε; (ΕΑΝ ΝΑΙ) Περίπου πόσα τετραγωνικά μέτρα είναι τα μπαλκόνια του σπιτιού σας;

Όχι, δεν έχω μπαλκόνια 777
Δεν γνωρίζω 888
Δεν απαντώ 999

Έχετε ακάλυπτο χώρο στο σπίτι στο οποίο κατοικείτε; (ΕΑΝ ΝΑΙ) Περίπου πόσα τετραγωνικά μέτρα είναι ο ακάλυπτος του σπιτιού ;

Όχι, δεν έχω ακάλυπτο 777
Δεν γνωρίζω 888
Δεν απαντώ 999

Ποια από τα παρακάτω αγαθά διαθέτει το νοικοκυριό σας; (ΔΙΑΒΑΣΤΕ)	ΝΑΙ	ΟΧΙ	ΔΓ/ΔΑ
Ηλεκτρονικό Υπολογιστή;	1	2	9
Laptop / Notebook;	1	2	9

IPAD;	1	2	9
Κλιματιστικό;	1	2	9
DVD;	1	2	9
NOVA;	1	2	9
Internet	1	2	9
Wi-Fi	1	2	9
Ηλιακό Θερμοσίφωνα	1	2	9

Και η προσωπική οικονομική σας κατάσταση τον επόμενο χρόνο, πιστεύετε ότι θα χειροτερεύσει πολύ, θα χειροτερεύσει λίγο, θα παραμείνει στάσιμη, θα καλυτερεύσει λίγο ή θα καλυτερεύσει πολύ;

Θα χειροτερεύσει πολύ 1
Θα χειροτερεύσει λίγο 2
Θα παραμείνει στάσιμη 3
Θα καλυτερεύσει λίγο 4
Θα καλυτερεύσει πολύ 5
ΔΓ/ΔΑ 9

Εσείς προσωπικά, στην παρούσα οικονομική συγκυρία αισθάνεστε ότι είστε εκτεθειμένος/η στον κίνδυνο της φτώχειας καθόλου, λίγο, αρκετά ή πολύ;

Καθόλου 1
Λίγο 2
Αρκετά 3
Πολύ 4
ΔΓ/ΔΑ 9

Ποιες πηγές ενημέρωσης θεωρείτε ποιο αξιόπιστες; (ΑΥΘΟΡΜΗΤΕΣ ΠΟΛΛΑΠΛΕΣ ΑΠΑΝΤΗΣΕΙΣ)

Τις εφημερίδες 1
Την Τηλεόραση 2
Το Ραδιόφωνο 3
Το Διαδίκτυο/Ιντερνετ 4
Άλλη (ποια; Παρακαλώ σημειώστε______________) 6
Καμμία (ΑΥΘΟΡΜΗΤΑ) 7
ΔΓ/ΔΑ 9

Τελειώνοντας, που θα τοποθετούσατε το συνολικό μηνιαίο οικογενειακό σας εισόδημα, από όλες τις πηγές, συμπεριλαμβανομένων των άλλων μελών της οικογενείας σας και του δικού σας, [λαμβάνοντας υπόψιν όλες τις πηγές, όπως μισθοί, υπερωρίες, εισοδήματα από ενοίκια, μερική απασχόληση, συντάξεις κτλ.]; (ΔΙΑΒΑΣΤΕ)

Α. Καθόλου εισοδήματα	Β. Έως 500 €	Γ. 501 – 1.000 €	Δ. 1.001 – 1.500 €	Ε. 1.501 – 2.000 €	ΣΤ. 2.001 – 3.000 €	Ζ. Πάνω από 3.000 €	ΔΓ/ΔΑ
1	2	3	4	5	6	7	9

Θα επιθυμούσατε να συμμετέχετε στο μέλλον σε online (διαδικτυακές) έρευνες; (ΑΝ ΝΑΙ) Θα μπορούσατε να μου δώσετε το e-mail σας έτσι ώστε να συμμετάσχετε στις έρευνες που διεξάγονται μέσω διαδικτύου; (Παρακαλώ σημειώστε την ηλεκτρονική διεύθυνση του ερωτώμενου)

Δεν χρησιμοποιώ e-mail (ΑΥΘΟΡΜΗΤΑ) 7
Δεν θυμάμαι το e-mail μου 8
Δεν επιθυμώ να συμμετέχω / Δεν θέλω να σας δώσω το e-mail 9

ΗΜ/ΝΙΑ:			1 3
ΩΡΑ ΕΝΑΡΞΗΣ			
ΩΡΑ ΛΗΞΗΣ			
Ονοματεπώνυμο Συνεντευκτή:			
Κωδικός Συνεντευκτή:			

Ευχαριστούμε για τη συνεργασία σας
ΥΠΟΓΡΑΦΗ ΣΥΝΕΝΤΕΥΚΤΗ

Δηλώνω υπεύθυνα ότι η συνέντευξη πραγματοποιήθηκε σύμφωνα με τις οδηγίες του Ινστιτούτου VPRC,
τον Κώδικα Δεοντολογίας ESOMAR/ΣΕΔΕΑ και το ν. 2472/97.

Annex IV – Time series of appliances’ frequencies of use for each water user category (water user type and water conservation level)

The following tables present the frequencies of use of the different in house appliances of the common Athenian household per water user type and per water conservation level.

Average water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.71	1.43	0.16	3.94	0.07	0.31	0.30
Feb-86	1.71	1.43	0.16	3.94	0.07	0.31	0.30
Mar-86	1.71	1.43	0.16	3.94	0.07	0.31	0.30
Apr-86	1.71	1.43	0.16	3.94	0.10	0.44	0.42
May-86	1.71	1.43	0.16	3.94	0.10	0.44	0.42
Jun-86	1.71	1.43	0.16	3.94	0.14	0.61	0.58
Jul-86	1.71	1.43	0.16	3.94	0.14	0.61	0.58
Aug-86	1.71	1.43	0.16	3.94	0.14	0.61	0.58
Sep-86	1.71	1.43	0.16	3.94	0.14	0.61	0.58
Oct-86	1.71	1.43	0.16	3.94	0.10	0.44	0.42
Nov-86	1.71	1.43	0.16	3.94	0.10	0.44	0.42
Dec-86	1.71	1.43	0.16	3.94	0.07	0.31	0.30
Jan-87	1.81	1.51	0.17	4.17	0.07	0.33	0.32
Feb-87	1.81	1.51	0.17	4.17	0.07	0.33	0.32
Mar-87	1.81	1.51	0.17	4.17	0.07	0.33	0.32
Apr-87	1.81	1.51	0.17	4.17	0.10	0.47	0.44
May-87	1.81	1.51	0.17	4.17	0.10	0.47	0.44
Jun-87	1.81	1.51	0.17	4.17	0.14	0.64	0.61
Jul-87	1.81	1.51	0.17	4.17	0.14	0.64	0.61
Aug-87	1.81	1.51	0.17	4.17	0.14	0.64	0.61
Sep-87	1.81	1.51	0.17	4.17	0.14	0.64	0.61
Oct-87	1.81	1.51	0.17	4.17	0.10	0.47	0.44
Nov-87	1.81	1.51	0.17	4.17	0.10	0.47	0.44
Dec-87	1.81	1.51	0.17	4.17	0.07	0.33	0.32
Jan-88	1.91	1.60	0.18	4.41	0.08	0.35	0.33
Feb-88	1.91	1.60	0.18	4.41	0.08	0.35	0.33
Mar-88	1.91	1.60	0.18	4.41	0.08	0.35	0.33
Apr-88	1.91	1.60	0.18	4.41	0.11	0.49	0.47
May-88	1.91	1.60	0.18	4.41	0.11	0.49	0.47
Jun-88	1.91	1.60	0.18	4.41	0.15	0.68	0.65
Jul-88	1.91	1.60	0.18	4.41	0.15	0.68	0.65
Aug-88	1.91	1.60	0.18	4.41	0.15	0.68	0.65
Sep-88	1.91	1.60	0.18	4.41	0.15	0.68	0.65
Oct-88	1.91	1.60	0.18	4.41	0.11	0.49	0.47
Nov-88	1.91	1.60	0.18	4.41	0.11	0.49	0.47
Dec-88	1.91	1.60	0.18	4.41	0.08	0.35	0.33

Average water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-89	2.01	1.68	0.19	4.65	0.08	0.37	0.35
Feb-89	2.01	1.68	0.19	4.65	0.08	0.37	0.35
Mar-89	2.01	1.68	0.19	4.65	0.08	0.37	0.35
Apr-89	2.01	1.68	0.19	4.65	0.12	0.52	0.49
May-89	2.01	1.68	0.19	4.65	0.12	0.52	0.49
Jun-89	2.01	1.68	0.19	4.65	0.16	0.72	0.68
Jul-89	2.01	1.68	0.19	4.65	0.16	0.72	0.68
Aug-89	2.01	1.68	0.19	4.65	0.16	0.72	0.68
Sep-89	2.01	1.68	0.19	4.65	0.16	0.72	0.68
Oct-89	2.01	1.68	0.19	4.65	0.12	0.52	0.49
Nov-89	2.01	1.68	0.19	4.65	0.12	0.52	0.49
Dec-89	2.01	1.68	0.19	4.65	0.08	0.37	0.35
Jan-90	2.12	1.77	0.20	4.88	0.09	0.39	0.37
Feb-90	2.12	1.77	0.20	4.88	0.09	0.39	0.37
Mar-90	2.12	1.77	0.20	4.88	0.09	0.39	0.37
Apr-90	2.12	1.77	0.20	4.88	0.12	0.55	0.52
May-90	2.12	1.77	0.20	4.88	0.12	0.55	0.52
Jun-90	2.12	1.77	0.20	4.88	0.17	0.75	0.71
Jul-90	2.12	1.77	0.20	4.88	0.17	0.75	0.71
Aug-90	2.12	1.77	0.20	4.88	0.17	0.75	0.71
Sep-90	2.12	1.77	0.20	4.88	0.17	0.75	0.71
Oct-90	2.12	1.77	0.20	4.88	0.12	0.55	0.52
Nov-90	2.12	1.77	0.20	4.88	0.12	0.55	0.52
Dec-90	2.12	1.77	0.20	4.88	0.09	0.39	0.37
Jan-91	2.14	1.79	0.20	4.94	0.09	0.39	0.37
Feb-91	2.14	1.79	0.20	4.94	0.09	0.39	0.37
Mar-91	2.14	1.79	0.20	4.94	0.09	0.39	0.37
Apr-91	2.14	1.79	0.20	4.94	0.12	0.55	0.52
May-91	2.14	1.79	0.20	4.94	0.12	0.55	0.52
Jun-91	2.14	1.79	0.20	4.94	0.17	0.76	0.72
Jul-91	2.14	1.79	0.20	4.94	0.17	0.76	0.72
Aug-91	2.14	1.79	0.20	4.94	0.17	0.76	0.72
Sep-91	2.14	1.79	0.20	4.94	0.17	0.76	0.72
Oct-91	2.14	1.79	0.20	4.94	0.12	0.55	0.52
Nov-91	2.14	1.79	0.20	4.94	0.12	0.55	0.52
Dec-91	2.14	1.79	0.20	4.94	0.09	0.39	0.37
Jan-92	2.16	1.80	0.20	4.99	0.09	0.40	0.38
Feb-92	2.16	1.80	0.20	4.99	0.09	0.40	0.38
Mar-92	2.16	1.80	0.20	4.99	0.09	0.40	0.38
Apr-92	2.16	1.80	0.20	4.99	0.13	0.56	0.53
May-92	2.16	1.80	0.20	4.99	0.13	0.56	0.53
Jun-92	2.16	1.80	0.20	4.99	0.17	0.77	0.73
Jul-92	2.16	1.80	0.20	4.99	0.17	0.77	0.73
Aug-92	2.16	1.80	0.20	4.99	0.17	0.77	0.73
Sep-92	2.16	1.80	0.20	4.99	0.17	0.77	0.73
Oct-92	2.16	1.80	0.20	4.99	0.13	0.56	0.53
Nov-92	2.16	1.80	0.20	4.99	0.13	0.56	0.53
Dec-92	2.16	1.80	0.20	4.99	0.09	0.40	0.38
Jan-93	2.18	1.82	0.20	5.04	0.09	0.40	0.38
Feb-93	2.18	1.82	0.20	5.04	0.09	0.40	0.38
Mar-93	2.18	1.82	0.20	5.04	0.09	0.40	0.38
Apr-93	2.18	1.82	0.20	5.04	0.13	0.56	0.53

Average water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
May-93	2.18	1.82	0.20	5.04	0.13	0.56	0.53
Jun-93	2.18	1.82	0.20	5.04	0.17	0.78	0.74
Jul-93	2.18	1.82	0.20	5.04	0.17	0.78	0.74
Aug-93	2.18	1.82	0.20	5.04	0.17	0.78	0.74
Sep-93	2.18	1.82	0.20	5.04	0.17	0.78	0.74
Oct-93	2.18	1.82	0.20	5.04	0.13	0.56	0.53
Nov-93	2.18	1.82	0.20	5.04	0.13	0.56	0.53
Dec-93	2.18	1.82	0.20	5.04	0.09	0.40	0.38
Jan-94	2.21	1.84	0.21	5.09	0.09	0.41	0.39
Feb-94	2.21	1.84	0.21	5.09	0.09	0.41	0.39
Mar-94	2.21	1.84	0.21	5.09	0.09	0.41	0.39
Apr-94	2.21	1.84	0.21	5.09	0.13	0.57	0.54
May-94	2.21	1.84	0.21	5.09	0.13	0.57	0.54
Jun-94	2.21	1.84	0.21	5.09	0.18	0.78	0.74
Jul-94	2.21	1.84	0.21	5.09	0.18	0.78	0.74
Aug-94	2.21	1.84	0.21	5.09	0.18	0.78	0.74
Sep-94	2.21	1.84	0.21	5.09	0.18	0.78	0.74
Oct-94	2.21	1.84	0.21	5.09	0.13	0.57	0.54
Nov-94	2.21	1.84	0.21	5.09	0.13	0.57	0.54
Dec-94	2.21	1.84	0.21	5.09	0.09	0.41	0.39
Jan-95	2.23	1.86	0.21	5.14	0.09	0.41	0.39
Feb-95	2.23	1.86	0.21	5.14	0.09	0.41	0.39
Mar-95	2.23	1.86	0.21	5.14	0.09	0.41	0.39
Apr-95	2.23	1.86	0.21	5.14	0.13	0.57	0.54
May-95	2.23	1.86	0.21	5.14	0.13	0.57	0.54
Jun-95	2.23	1.86	0.21	5.14	0.18	0.79	0.75
Jul-95	2.23	1.86	0.21	5.14	0.18	0.79	0.75
Aug-95	2.23	1.86	0.21	5.14	0.18	0.79	0.75
Sep-95	2.23	1.86	0.21	5.14	0.18	0.79	0.75
Oct-95	2.23	1.86	0.21	5.14	0.13	0.57	0.54
Nov-95	2.23	1.86	0.21	5.14	0.13	0.57	0.54
Dec-95	2.23	1.86	0.21	5.14	0.09	0.41	0.39
Jan-96	2.25	1.88	0.21	5.19	0.09	0.41	0.39
Feb-96	2.25	1.88	0.21	5.19	0.09	0.41	0.39
Mar-96	2.25	1.88	0.21	5.19	0.09	0.41	0.39
Apr-96	2.25	1.88	0.21	5.19	0.13	0.58	0.55
May-96	2.25	1.88	0.21	5.19	0.13	0.58	0.55
Jun-96	2.25	1.88	0.21	5.19	0.18	0.80	0.76
Jul-96	2.25	1.88	0.21	5.19	0.18	0.80	0.76
Aug-96	2.25	1.88	0.21	5.19	0.18	0.80	0.76
Sep-96	2.25	1.88	0.21	5.19	0.18	0.80	0.76
Oct-96	2.25	1.88	0.21	5.19	0.13	0.58	0.55
Nov-96	2.25	1.88	0.21	5.19	0.13	0.58	0.55
Dec-96	2.25	1.88	0.21	5.19	0.09	0.41	0.39
Jan-97	2.27	1.90	0.21	5.24	0.09	0.42	0.40
Feb-97	2.27	1.90	0.21	5.24	0.09	0.42	0.40
Mar-97	2.27	1.90	0.21	5.24	0.09	0.42	0.40
Apr-97	2.27	1.90	0.21	5.24	0.13	0.59	0.56
May-97	2.27	1.90	0.21	5.24	0.13	0.59	0.56
Jun-97	2.27	1.90	0.21	5.24	0.18	0.81	0.77
Jul-97	2.27	1.90	0.21	5.24	0.18	0.81	0.77
Aug-97	2.27	1.90	0.21	5.24	0.18	0.81	0.77

Average water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Sep-97	2.27	1.90	0.21	5.24	0.18	0.81	0.77
Oct-97	2.27	1.90	0.21	5.24	0.13	0.59	0.56
Nov-97	2.27	1.90	0.21	5.24	0.13	0.59	0.56
Dec-97	2.27	1.90	0.21	5.24	0.09	0.42	0.40
Jan-98	2.29	1.92	0.21	5.29	0.09	0.42	0.40
Feb-98	2.29	1.92	0.21	5.29	0.09	0.42	0.40
Mar-98	2.29	1.92	0.21	5.29	0.09	0.42	0.40
Apr-98	2.29	1.92	0.21	5.29	0.13	0.59	0.56
May-98	2.29	1.92	0.21	5.29	0.13	0.59	0.56
Jun-98	2.29	1.92	0.21	5.29	0.18	0.82	0.77
Jul-98	2.29	1.92	0.21	5.29	0.18	0.82	0.77
Aug-98	2.29	1.92	0.21	5.29	0.18	0.82	0.77
Sep-98	2.29	1.92	0.21	5.29	0.18	0.82	0.77
Oct-98	2.29	1.92	0.21	5.29	0.13	0.59	0.56
Nov-98	2.29	1.92	0.21	5.29	0.13	0.59	0.56
Dec-98	2.29	1.92	0.21	5.29	0.09	0.42	0.40

Low water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.51	1.43	0.03	3.94	0.04	0.22	0.02
Feb-86	1.51	1.43	0.03	3.94	0.04	0.22	0.02
Mar-86	1.51	1.43	0.03	3.94	0.04	0.22	0.02
Apr-86	1.51	1.43	0.03	3.94	0.05	0.31	0.03
May-86	1.51	1.43	0.03	3.94	0.05	0.31	0.03
Jun-86	1.51	1.43	0.03	3.94	0.07	0.43	0.04
Jul-86	1.51	1.43	0.03	3.94	0.07	0.43	0.04
Aug-86	1.51	1.43	0.03	3.94	0.07	0.43	0.04
Sep-86	1.51	1.43	0.03	3.94	0.07	0.43	0.04
Oct-86	1.51	1.43	0.03	3.94	0.05	0.31	0.03
Nov-86	1.51	1.43	0.03	3.94	0.05	0.31	0.03
Dec-86	1.51	1.43	0.03	3.94	0.04	0.22	0.02
Jan-87	1.60	1.51	0.03	4.17	0.04	0.23	0.02
Feb-87	1.60	1.51	0.03	4.17	0.04	0.23	0.02
Mar-87	1.60	1.51	0.03	4.17	0.04	0.23	0.02
Apr-87	1.60	1.51	0.03	4.17	0.06	0.33	0.03
May-87	1.60	1.51	0.03	4.17	0.06	0.33	0.03
Jun-87	1.60	1.51	0.03	4.17	0.08	0.45	0.04
Jul-87	1.60	1.51	0.03	4.17	0.08	0.45	0.04
Aug-87	1.60	1.51	0.03	4.17	0.08	0.45	0.04
Sep-87	1.60	1.51	0.03	4.17	0.08	0.45	0.04
Oct-87	1.60	1.51	0.03	4.17	0.06	0.33	0.03
Nov-87	1.60	1.51	0.03	4.17	0.06	0.33	0.03
Dec-87	1.60	1.51	0.03	4.17	0.04	0.23	0.02
Jan-88	1.69	1.60	0.03	4.43	0.04	0.25	0.02
Feb-88	1.69	1.60	0.03	4.43	0.04	0.25	0.02
Mar-88	1.69	1.60	0.03	4.43	0.04	0.25	0.02
Apr-88	1.69	1.60	0.03	4.43	0.06	0.35	0.03
May-88	1.69	1.60	0.03	4.43	0.06	0.35	0.03
Jun-88	1.69	1.60	0.03	4.43	0.08	0.48	0.04
Jul-88	1.69	1.60	0.03	4.43	0.08	0.48	0.04
Aug-88	1.69	1.60	0.03	4.43	0.08	0.48	0.04
Sep-88	1.69	1.60	0.03	4.43	0.08	0.48	0.04

Low water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Oct-88	1.69	1.60	0.03	4.43	0.06	0.35	0.03
Nov-88	1.69	1.60	0.03	4.43	0.06	0.35	0.03
Dec-88	1.69	1.60	0.03	4.43	0.04	0.25	0.02
Jan-89	1.79	1.70	0.04	4.69	0.04	0.26	0.02
Feb-89	1.79	1.70	0.04	4.69	0.04	0.26	0.02
Mar-89	1.79	1.70	0.04	4.69	0.04	0.26	0.02
Apr-89	1.79	1.70	0.04	4.69	0.06	0.37	0.03
May-89	1.79	1.70	0.04	4.69	0.06	0.37	0.03
Jun-89	1.79	1.70	0.04	4.69	0.09	0.51	0.04
Jul-89	1.79	1.70	0.04	4.69	0.09	0.51	0.04
Aug-89	1.79	1.70	0.04	4.69	0.09	0.51	0.04
Sep-89	1.79	1.70	0.04	4.69	0.09	0.51	0.04
Oct-89	1.79	1.70	0.04	4.69	0.06	0.37	0.03
Nov-89	1.79	1.70	0.04	4.69	0.06	0.37	0.03
Dec-89	1.79	1.70	0.04	4.69	0.04	0.26	0.02
Jan-90	1.82	1.72	0.04	4.75	0.05	0.27	0.02
Feb-90	1.82	1.72	0.04	4.75	0.05	0.27	0.02
Mar-90	1.82	1.72	0.04	4.75	0.05	0.27	0.02
Apr-90	1.82	1.72	0.04	4.75	0.06	0.37	0.03
May-90	1.82	1.72	0.04	4.75	0.06	0.37	0.03
Jun-90	1.82	1.72	0.04	4.75	0.09	0.51	0.04
Jul-90	1.82	1.72	0.04	4.75	0.09	0.51	0.04
Aug-90	1.82	1.72	0.04	4.75	0.09	0.51	0.04
Sep-90	1.82	1.72	0.04	4.75	0.09	0.51	0.04
Oct-90	1.82	1.72	0.04	4.75	0.06	0.37	0.03
Nov-90	1.82	1.72	0.04	4.75	0.06	0.37	0.03
Dec-90	1.82	1.72	0.04	4.75	0.05	0.27	0.02
Jan-91	1.84	1.74	0.04	4.81	0.05	0.27	0.02
Feb-91	1.84	1.74	0.04	4.81	0.05	0.27	0.02
Mar-91	1.84	1.74	0.04	4.81	0.05	0.27	0.02
Apr-91	1.84	1.74	0.04	4.81	0.06	0.38	0.03
May-91	1.84	1.74	0.04	4.81	0.06	0.38	0.03
Jun-91	1.84	1.74	0.04	4.81	0.09	0.52	0.05
Jul-91	1.84	1.74	0.04	4.81	0.09	0.52	0.05
Aug-91	1.84	1.74	0.04	4.81	0.09	0.52	0.05
Sep-91	1.84	1.74	0.04	4.81	0.09	0.52	0.05
Oct-91	1.84	1.74	0.04	4.81	0.06	0.38	0.03
Nov-91	1.84	1.74	0.04	4.81	0.06	0.38	0.03
Dec-91	1.84	1.74	0.04	4.81	0.05	0.27	0.02
Jan-92	1.86	1.76	0.04	4.88	0.05	0.27	0.02
Feb-92	1.86	1.76	0.04	4.88	0.05	0.27	0.02
Mar-92	1.86	1.76	0.04	4.88	0.05	0.27	0.02
Apr-92	1.86	1.76	0.04	4.88	0.07	0.38	0.03
May-92	1.86	1.76	0.04	4.88	0.07	0.38	0.03
Jun-92	1.86	1.76	0.04	4.88	0.09	0.53	0.05
Jul-92	1.86	1.76	0.04	4.88	0.09	0.53	0.05
Aug-92	1.86	1.76	0.04	4.88	0.09	0.53	0.05
Sep-92	1.86	1.76	0.04	4.88	0.09	0.53	0.05
Oct-92	1.86	1.76	0.04	4.88	0.07	0.38	0.03
Nov-92	1.86	1.76	0.04	4.88	0.07	0.38	0.03
Dec-92	1.86	1.76	0.04	4.88	0.05	0.27	0.02
Jan-93	1.89	1.79	0.04	4.94	0.05	0.28	0.02

Low water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Feb-93	1.89	1.79	0.04	4.94	0.05	0.28	0.02
Mar-93	1.89	1.79	0.04	4.94	0.05	0.28	0.02
Apr-93	1.89	1.79	0.04	4.94	0.07	0.39	0.03
May-93	1.89	1.79	0.04	4.94	0.07	0.39	0.03
Jun-93	1.89	1.79	0.04	4.94	0.09	0.53	0.05
Jul-93	1.89	1.79	0.04	4.94	0.09	0.53	0.05
Aug-93	1.89	1.79	0.04	4.94	0.09	0.53	0.05
Sep-93	1.89	1.79	0.04	4.94	0.09	0.53	0.05
Oct-93	1.89	1.79	0.04	4.94	0.07	0.39	0.03
Nov-93	1.89	1.79	0.04	4.94	0.07	0.39	0.03
Dec-93	1.89	1.79	0.04	4.94	0.05	0.28	0.02
Jan-94	1.91	1.81	0.04	5.00	0.05	0.28	0.02
Feb-94	1.91	1.81	0.04	5.00	0.05	0.28	0.02
Mar-94	1.91	1.81	0.04	5.00	0.05	0.28	0.02
Apr-94	1.91	1.81	0.04	5.00	0.07	0.39	0.03
May-94	1.91	1.81	0.04	5.00	0.07	0.39	0.03
Jun-94	1.91	1.81	0.04	5.00	0.09	0.54	0.05
Jul-94	1.91	1.81	0.04	5.00	0.09	0.54	0.05
Aug-94	1.91	1.81	0.04	5.00	0.09	0.54	0.05
Sep-94	1.91	1.81	0.04	5.00	0.09	0.54	0.05
Oct-94	1.91	1.81	0.04	5.00	0.07	0.39	0.03
Nov-94	1.91	1.81	0.04	5.00	0.07	0.39	0.03
Dec-94	1.91	1.81	0.04	5.00	0.05	0.28	0.02
Jan-95	1.94	1.83	0.04	5.07	0.05	0.28	0.02
Feb-95	1.94	1.83	0.04	5.07	0.05	0.28	0.02
Mar-95	1.94	1.83	0.04	5.07	0.05	0.28	0.02
Apr-95	1.94	1.83	0.04	5.07	0.07	0.40	0.03
May-95	1.94	1.83	0.04	5.07	0.07	0.40	0.03
Jun-95	1.94	1.83	0.04	5.07	0.09	0.55	0.05
Jul-95	1.94	1.83	0.04	5.07	0.09	0.55	0.05
Aug-95	1.94	1.83	0.04	5.07	0.09	0.55	0.05
Sep-95	1.94	1.83	0.04	5.07	0.09	0.55	0.05
Oct-95	1.94	1.83	0.04	5.07	0.07	0.40	0.03
Nov-95	1.94	1.83	0.04	5.07	0.07	0.40	0.03
Dec-95	1.94	1.83	0.04	5.07	0.05	0.28	0.02
Jan-96	1.96	1.86	0.04	5.13	0.05	0.29	0.03
Feb-96	1.96	1.86	0.04	5.13	0.05	0.29	0.03
Mar-96	1.96	1.86	0.04	5.13	0.05	0.29	0.03
Apr-96	1.96	1.86	0.04	5.13	0.07	0.40	0.04
May-96	1.96	1.86	0.04	5.13	0.07	0.40	0.04
Jun-96	1.96	1.86	0.04	5.13	0.09	0.56	0.05
Jul-96	1.96	1.86	0.04	5.13	0.09	0.56	0.05
Aug-96	1.96	1.86	0.04	5.13	0.09	0.56	0.05
Sep-96	1.96	1.86	0.04	5.13	0.09	0.56	0.05
Oct-96	1.96	1.86	0.04	5.13	0.07	0.40	0.04
Nov-96	1.96	1.86	0.04	5.13	0.07	0.40	0.04
Dec-96	1.96	1.86	0.04	5.13	0.05	0.29	0.03
Jan-97	1.99	1.88	0.04	5.20	0.05	0.29	0.03
Feb-97	1.99	1.88	0.04	5.20	0.05	0.29	0.03
Mar-97	1.99	1.88	0.04	5.20	0.05	0.29	0.03
Apr-97	1.99	1.88	0.04	5.20	0.07	0.41	0.04
May-97	1.99	1.88	0.04	5.20	0.07	0.41	0.04

Low water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jun-97	1.99	1.88	0.04	5.20	0.10	0.56	0.05
Jul-97	1.99	1.88	0.04	5.20	0.10	0.56	0.05
Aug-97	1.99	1.88	0.04	5.20	0.10	0.56	0.05
Sep-97	1.99	1.88	0.04	5.20	0.10	0.56	0.05
Oct-97	1.99	1.88	0.04	5.20	0.07	0.41	0.04
Nov-97	1.99	1.88	0.04	5.20	0.07	0.41	0.04
Dec-97	1.99	1.88	0.04	5.20	0.05	0.29	0.03
Jan-98	2.01	1.91	0.04	5.27	0.05	0.29	0.03
Feb-98	2.01	1.91	0.04	5.27	0.05	0.29	0.03
Mar-98	2.01	1.91	0.04	5.27	0.05	0.29	0.03
Apr-98	2.01	1.91	0.04	5.27	0.07	0.41	0.04
May-98	2.01	1.91	0.04	5.27	0.07	0.41	0.04
Jun-98	2.01	1.91	0.04	5.27	0.10	0.57	0.05
Jul-98	2.01	1.91	0.04	5.27	0.10	0.57	0.05
Aug-98	2.01	1.91	0.04	5.27	0.10	0.57	0.05
Sep-98	2.01	1.91	0.04	5.27	0.10	0.57	0.05
Oct-98	2.01	1.91	0.04	5.27	0.07	0.41	0.04
Nov-98	2.01	1.91	0.04	5.27	0.07	0.41	0.04
Dec-98	2.01	1.91	0.04	5.27	0.05	0.29	0.03

High water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.93	1.96	0.16	4.94	0.07	0.36	0.30
Feb-86	1.93	1.96	0.16	4.94	0.07	0.36	0.30
Mar-86	1.93	1.96	0.16	4.94	0.07	0.36	0.30
Apr-86	1.93	1.96	0.16	4.94	0.10	0.50	0.42
May-86	1.93	1.96	0.16	4.94	0.10	0.50	0.42
Jun-86	1.93	1.96	0.16	4.94	0.14	0.69	0.58
Jul-86	1.93	1.96	0.16	4.94	0.14	0.69	0.58
Aug-86	1.93	1.96	0.16	4.94	0.14	0.69	0.58
Sep-86	1.93	1.96	0.16	4.94	0.14	0.69	0.58
Oct-86	1.93	1.96	0.16	4.94	0.10	0.50	0.42
Nov-86	1.93	1.96	0.16	4.94	0.10	0.50	0.42
Dec-86	1.93	1.96	0.16	4.94	0.07	0.36	0.30
Jan-87	2.04	2.07	0.17	5.23	0.07	0.38	0.32
Feb-87	2.04	2.07	0.17	5.23	0.07	0.38	0.32
Mar-87	2.04	2.07	0.17	5.23	0.07	0.38	0.32
Apr-87	2.04	2.07	0.17	5.23	0.10	0.53	0.44
May-87	2.04	2.07	0.17	5.23	0.10	0.53	0.44
Jun-87	2.04	2.07	0.17	5.23	0.14	0.73	0.61
Jul-87	2.04	2.07	0.17	5.23	0.14	0.73	0.61
Aug-87	2.04	2.07	0.17	5.23	0.14	0.73	0.61
Sep-87	2.04	2.07	0.17	5.23	0.14	0.73	0.61
Oct-87	2.04	2.07	0.17	5.23	0.10	0.53	0.44
Nov-87	2.04	2.07	0.17	5.23	0.10	0.53	0.44
Dec-87	2.04	2.07	0.17	5.23	0.07	0.38	0.32
Jan-88	2.17	2.20	0.18	5.55	0.08	0.40	0.33
Feb-88	2.17	2.20	0.18	5.55	0.08	0.40	0.33
Mar-88	2.17	2.20	0.18	5.55	0.08	0.40	0.33
Apr-88	2.17	2.20	0.18	5.55	0.11	0.56	0.47
May-88	2.17	2.20	0.18	5.55	0.11	0.56	0.47
Jun-88	2.17	2.20	0.18	5.55	0.15	0.78	0.65

High water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jul-88	2.17	2.20	0.18	5.55	0.15	0.78	0.65
Aug-88	2.17	2.20	0.18	5.55	0.15	0.78	0.65
Sep-88	2.17	2.20	0.18	5.55	0.15	0.78	0.65
Oct-88	2.17	2.20	0.18	5.55	0.11	0.56	0.47
Nov-88	2.17	2.20	0.18	5.55	0.11	0.56	0.47
Dec-88	2.17	2.20	0.18	5.55	0.08	0.40	0.33
Jan-89	2.30	2.33	0.19	5.88	0.08	0.43	0.36
Feb-89	2.30	2.33	0.19	5.88	0.08	0.43	0.36
Mar-89	2.30	2.33	0.19	5.88	0.08	0.43	0.36
Apr-89	2.30	2.33	0.19	5.88	0.12	0.60	0.50
May-89	2.30	2.33	0.19	5.88	0.12	0.60	0.50
Jun-89	2.30	2.33	0.19	5.88	0.16	0.82	0.69
Jul-89	2.30	2.33	0.19	5.88	0.16	0.82	0.69
Aug-89	2.30	2.33	0.19	5.88	0.16	0.82	0.69
Sep-89	2.30	2.33	0.19	5.88	0.16	0.82	0.69
Oct-89	2.30	2.33	0.19	5.88	0.12	0.60	0.50
Nov-89	2.30	2.33	0.19	5.88	0.12	0.60	0.50
Dec-89	2.30	2.33	0.19	5.88	0.08	0.43	0.36
Jan-90	2.33	2.36	0.19	5.95	0.09	0.43	0.36
Feb-90	2.33	2.36	0.19	5.95	0.09	0.43	0.36
Mar-90	2.33	2.36	0.19	5.95	0.09	0.43	0.36
Apr-90	2.33	2.36	0.19	5.95	0.12	0.60	0.50
May-90	2.33	2.36	0.19	5.95	0.12	0.60	0.50
Jun-90	2.33	2.36	0.19	5.95	0.16	0.83	0.70
Jul-90	2.33	2.36	0.19	5.95	0.16	0.83	0.70
Aug-90	2.33	2.36	0.19	5.95	0.16	0.83	0.70
Sep-90	2.33	2.36	0.19	5.95	0.16	0.83	0.70
Oct-90	2.33	2.36	0.19	5.95	0.12	0.60	0.50
Nov-90	2.33	2.36	0.19	5.95	0.12	0.60	0.50
Dec-90	2.33	2.36	0.19	5.95	0.09	0.43	0.36
Jan-91	2.36	2.39	0.19	6.03	0.09	0.44	0.36
Feb-91	2.36	2.39	0.19	6.03	0.09	0.44	0.36
Mar-91	2.36	2.39	0.19	6.03	0.09	0.44	0.36
Apr-91	2.36	2.39	0.19	6.03	0.12	0.61	0.51
May-91	2.36	2.39	0.19	6.03	0.12	0.61	0.51
Jun-91	2.36	2.39	0.19	6.03	0.17	0.84	0.70
Jul-91	2.36	2.39	0.19	6.03	0.17	0.84	0.70
Aug-91	2.36	2.39	0.19	6.03	0.17	0.84	0.70
Sep-91	2.36	2.39	0.19	6.03	0.17	0.84	0.70
Oct-91	2.36	2.39	0.19	6.03	0.12	0.61	0.51
Nov-91	2.36	2.39	0.19	6.03	0.12	0.61	0.51
Dec-91	2.36	2.39	0.19	6.03	0.09	0.44	0.36
Jan-92	2.39	2.42	0.20	6.11	0.09	0.44	0.37
Feb-92	2.39	2.42	0.20	6.11	0.09	0.44	0.37
Mar-92	2.39	2.42	0.20	6.11	0.09	0.44	0.37
Apr-92	2.39	2.42	0.20	6.11	0.12	0.62	0.52
May-92	2.39	2.42	0.20	6.11	0.12	0.62	0.52
Jun-92	2.39	2.42	0.20	6.11	0.17	0.86	0.71
Jul-92	2.39	2.42	0.20	6.11	0.17	0.86	0.71
Aug-92	2.39	2.42	0.20	6.11	0.17	0.86	0.71
Sep-92	2.39	2.42	0.20	6.11	0.17	0.86	0.71
Oct-92	2.39	2.42	0.20	6.11	0.12	0.62	0.52

High water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Nov-92	2.39	2.42	0.20	6.11	0.12	0.62	0.52
Dec-92	2.39	2.42	0.20	6.11	0.09	0.44	0.37
Jan-93	2.42	2.45	0.20	6.19	0.09	0.45	0.37
Feb-93	2.42	2.45	0.20	6.19	0.09	0.45	0.37
Mar-93	2.42	2.45	0.20	6.19	0.09	0.45	0.37
Apr-93	2.42	2.45	0.20	6.19	0.12	0.63	0.52
May-93	2.42	2.45	0.20	6.19	0.12	0.63	0.52
Jun-93	2.42	2.45	0.20	6.19	0.17	0.87	0.72
Jul-93	2.42	2.45	0.20	6.19	0.17	0.87	0.72
Aug-93	2.42	2.45	0.20	6.19	0.17	0.87	0.72
Sep-93	2.42	2.45	0.20	6.19	0.17	0.87	0.72
Oct-93	2.42	2.45	0.20	6.19	0.12	0.63	0.52
Nov-93	2.42	2.45	0.20	6.19	0.12	0.63	0.52
Dec-93	2.42	2.45	0.20	6.19	0.09	0.45	0.37
Jan-94	2.45	2.49	0.20	6.27	0.09	0.45	0.38
Feb-94	2.45	2.49	0.20	6.27	0.09	0.45	0.38
Mar-94	2.45	2.49	0.20	6.27	0.09	0.45	0.38
Apr-94	2.45	2.49	0.20	6.27	0.13	0.64	0.53
May-94	2.45	2.49	0.20	6.27	0.13	0.64	0.53
Jun-94	2.45	2.49	0.20	6.27	0.17	0.88	0.73
Jul-94	2.45	2.49	0.20	6.27	0.17	0.88	0.73
Aug-94	2.45	2.49	0.20	6.27	0.17	0.88	0.73
Sep-94	2.45	2.49	0.20	6.27	0.17	0.88	0.73
Oct-94	2.45	2.49	0.20	6.27	0.13	0.64	0.53
Nov-94	2.45	2.49	0.20	6.27	0.13	0.64	0.53
Dec-94	2.45	2.49	0.20	6.27	0.09	0.45	0.38
Jan-95	2.48	2.52	0.21	6.35	0.09	0.46	0.38
Feb-95	2.48	2.52	0.21	6.35	0.09	0.46	0.38
Mar-95	2.48	2.52	0.21	6.35	0.09	0.46	0.38
Apr-95	2.48	2.52	0.21	6.35	0.13	0.64	0.54
May-95	2.48	2.52	0.21	6.35	0.13	0.64	0.54
Jun-95	2.48	2.52	0.21	6.35	0.18	0.89	0.74
Jul-95	2.48	2.52	0.21	6.35	0.18	0.89	0.74
Aug-95	2.48	2.52	0.21	6.35	0.18	0.89	0.74
Sep-95	2.48	2.52	0.21	6.35	0.18	0.89	0.74
Oct-95	2.48	2.52	0.21	6.35	0.13	0.64	0.54
Nov-95	2.48	2.52	0.21	6.35	0.13	0.64	0.54
Dec-95	2.48	2.52	0.21	6.35	0.09	0.46	0.38
Jan-96	2.51	2.55	0.21	6.43	0.09	0.47	0.39
Feb-96	2.51	2.55	0.21	6.43	0.09	0.47	0.39
Mar-96	2.51	2.55	0.21	6.43	0.09	0.47	0.39
Apr-96	2.51	2.55	0.21	6.43	0.13	0.65	0.54
May-96	2.51	2.55	0.21	6.43	0.13	0.65	0.54
Jun-96	2.51	2.55	0.21	6.43	0.18	0.90	0.75
Jul-96	2.51	2.55	0.21	6.43	0.18	0.90	0.75
Aug-96	2.51	2.55	0.21	6.43	0.18	0.90	0.75
Sep-96	2.51	2.55	0.21	6.43	0.18	0.90	0.75
Oct-96	2.51	2.55	0.21	6.43	0.13	0.65	0.54
Nov-96	2.51	2.55	0.21	6.43	0.13	0.65	0.54
Dec-96	2.51	2.55	0.21	6.43	0.09	0.47	0.39
Jan-97	2.55	2.58	0.21	6.52	0.09	0.47	0.39
Feb-97	2.55	2.58	0.21	6.52	0.09	0.47	0.39

High water user – Zero water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Mar-97	2.55	2.58	0.21	6.52	0.09	0.47	0.39
Apr-97	2.55	2.58	0.21	6.52	0.13	0.66	0.55
May-97	2.55	2.58	0.21	6.52	0.13	0.66	0.55
Jun-97	2.55	2.58	0.21	6.52	0.18	0.91	0.76
Jul-97	2.55	2.58	0.21	6.52	0.18	0.91	0.76
Aug-97	2.55	2.58	0.21	6.52	0.18	0.91	0.76
Sep-97	2.55	2.58	0.21	6.52	0.18	0.91	0.76
Oct-97	2.55	2.58	0.21	6.52	0.13	0.66	0.55
Nov-97	2.55	2.58	0.21	6.52	0.13	0.66	0.55
Dec-97	2.55	2.58	0.21	6.52	0.09	0.47	0.39
Jan-98	2.58	2.62	0.21	6.60	0.09	0.48	0.40
Feb-98	2.58	2.62	0.21	6.60	0.09	0.48	0.40
Mar-98	2.58	2.62	0.21	6.60	0.09	0.48	0.40
Apr-98	2.58	2.62	0.21	6.60	0.13	0.67	0.56
May-98	2.58	2.62	0.21	6.60	0.13	0.67	0.56
Jun-98	2.58	2.62	0.21	6.60	0.18	0.92	0.77
Jul-98	2.58	2.62	0.21	6.60	0.18	0.92	0.77
Aug-98	2.58	2.62	0.21	6.60	0.18	0.92	0.77
Sep-98	2.58	2.62	0.21	6.60	0.18	0.92	0.77
Oct-98	2.58	2.62	0.21	6.60	0.13	0.67	0.56
Nov-98	2.58	2.62	0.21	6.60	0.13	0.67	0.56
Dec-98	2.58	2.62	0.21	6.60	0.09	0.48	0.40

Average water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.49	1.30	0.15	3.19	0.07	0.31	0.23
Feb-86	1.49	1.30	0.15	3.19	0.07	0.31	0.23
Mar-86	1.49	1.30	0.15	3.19	0.07	0.31	0.23
Apr-86	1.49	1.30	0.15	3.19	0.09	0.43	0.33
May-86	1.49	1.30	0.15	3.19	0.09	0.43	0.33
Jun-86	1.49	1.30	0.15	3.19	0.13	0.59	0.45
Jul-86	1.49	1.30	0.15	3.19	0.13	0.59	0.45
Aug-86	1.49	1.30	0.15	3.19	0.13	0.59	0.45
Sep-86	1.49	1.30	0.15	3.19	0.13	0.59	0.45
Oct-86	1.49	1.30	0.15	3.19	0.09	0.43	0.33
Nov-86	1.49	1.30	0.15	3.19	0.09	0.43	0.33
Dec-86	1.49	1.30	0.15	3.19	0.07	0.31	0.23
Jan-87	1.58	1.38	0.16	3.38	0.07	0.33	0.25
Feb-87	1.58	1.38	0.16	3.38	0.07	0.33	0.25
Mar-87	1.58	1.38	0.16	3.38	0.07	0.33	0.25
Apr-87	1.58	1.38	0.16	3.38	0.10	0.46	0.35
May-87	1.58	1.38	0.16	3.38	0.10	0.46	0.35
Jun-87	1.58	1.38	0.16	3.38	0.14	0.63	0.48
Jul-87	1.58	1.38	0.16	3.38	0.14	0.63	0.48
Aug-87	1.58	1.38	0.16	3.38	0.14	0.63	0.48
Sep-87	1.58	1.38	0.16	3.38	0.14	0.63	0.48
Oct-87	1.58	1.38	0.16	3.38	0.10	0.46	0.35
Nov-87	1.58	1.38	0.16	3.38	0.10	0.46	0.35
Dec-87	1.58	1.38	0.16	3.38	0.07	0.33	0.25
Jan-88	1.67	1.46	0.17	3.57	0.08	0.34	0.26
Feb-88	1.67	1.46	0.17	3.57	0.08	0.34	0.26

Average water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Mar-88	1.67	1.46	0.17	3.57	0.08	0.34	0.26
Apr-88	1.67	1.46	0.17	3.57	0.11	0.48	0.36
May-88	1.67	1.46	0.17	3.57	0.11	0.48	0.36
Jun-88	1.67	1.46	0.17	3.57	0.15	0.67	0.50
Jul-88	1.67	1.46	0.17	3.57	0.15	0.67	0.50
Aug-88	1.67	1.46	0.17	3.57	0.15	0.67	0.50
Sep-88	1.67	1.46	0.17	3.57	0.15	0.67	0.50
Oct-88	1.67	1.46	0.17	3.57	0.11	0.48	0.36
Nov-88	1.67	1.46	0.17	3.57	0.11	0.48	0.36
Dec-88	1.67	1.46	0.17	3.57	0.08	0.34	0.26
Jan-89	1.76	1.53	0.18	3.76	0.08	0.36	0.27
Feb-89	1.76	1.53	0.18	3.76	0.08	0.36	0.27
Mar-89	1.76	1.53	0.18	3.76	0.08	0.36	0.27
Apr-89	1.76	1.53	0.18	3.76	0.11	0.51	0.38
May-89	1.76	1.53	0.18	3.76	0.11	0.51	0.38
Jun-89	1.76	1.53	0.18	3.76	0.15	0.70	0.53
Jul-89	1.76	1.53	0.18	3.76	0.15	0.70	0.53
Aug-89	1.76	1.53	0.18	3.76	0.15	0.70	0.53
Sep-89	1.76	1.53	0.18	3.76	0.15	0.70	0.53
Oct-89	1.76	1.53	0.18	3.76	0.11	0.51	0.38
Nov-89	1.76	1.53	0.18	3.76	0.11	0.51	0.38
Dec-89	1.76	1.53	0.18	3.76	0.08	0.36	0.27
Jan-90	1.85	1.61	0.19	3.96	0.08	0.38	0.29
Feb-90	1.85	1.61	0.19	3.96	0.08	0.38	0.29
Mar-90	1.85	1.61	0.19	3.96	0.08	0.38	0.29
Apr-90	1.85	1.61	0.19	3.96	0.12	0.53	0.40
May-90	1.85	1.61	0.19	3.96	0.12	0.53	0.40
Jun-90	1.85	1.61	0.19	3.96	0.16	0.74	0.56
Jul-90	1.85	1.61	0.19	3.96	0.16	0.74	0.56
Aug-90	1.85	1.61	0.19	3.96	0.16	0.74	0.56
Sep-90	1.85	1.61	0.19	3.96	0.16	0.74	0.56
Oct-90	1.85	1.61	0.19	3.96	0.12	0.53	0.40
Nov-90	1.85	1.61	0.19	3.96	0.12	0.53	0.40
Dec-90	1.85	1.61	0.19	3.96	0.08	0.38	0.29
Jan-91	1.87	1.63	0.19	4.00	0.08	0.39	0.29
Feb-91	1.87	1.63	0.19	4.00	0.08	0.39	0.29
Mar-91	1.87	1.63	0.19	4.00	0.08	0.39	0.29
Apr-91	1.87	1.63	0.19	4.00	0.12	0.54	0.41
May-91	1.87	1.63	0.19	4.00	0.12	0.54	0.41
Jun-91	1.87	1.63	0.19	4.00	0.16	0.74	0.56
Jul-91	1.87	1.63	0.19	4.00	0.16	0.74	0.56
Aug-91	1.87	1.63	0.19	4.00	0.16	0.74	0.56
Sep-91	1.87	1.63	0.19	4.00	0.16	0.74	0.56
Oct-91	1.87	1.63	0.19	4.00	0.12	0.54	0.41
Nov-91	1.87	1.63	0.19	4.00	0.12	0.54	0.41
Dec-91	1.87	1.63	0.19	4.00	0.08	0.39	0.29
Jan-92	1.89	1.65	0.19	4.04	0.09	0.39	0.29
Feb-92	1.89	1.65	0.19	4.04	0.09	0.39	0.29
Mar-92	1.89	1.65	0.19	4.04	0.09	0.39	0.29
Apr-92	1.89	1.65	0.19	4.04	0.12	0.55	0.41
May-92	1.89	1.65	0.19	4.04	0.12	0.55	0.41
Jun-92	1.89	1.65	0.19	4.04	0.17	0.75	0.57

Average water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jul-92	1.89	1.65	0.19	4.04	0.17	0.75	0.57
Aug-92	1.89	1.65	0.19	4.04	0.17	0.75	0.57
Sep-92	1.89	1.65	0.19	4.04	0.17	0.75	0.57
Oct-92	1.89	1.65	0.19	4.04	0.12	0.55	0.41
Nov-92	1.89	1.65	0.19	4.04	0.12	0.55	0.41
Dec-92	1.89	1.65	0.19	4.04	0.09	0.39	0.29
Jan-93	1.91	1.66	0.19	4.08	0.09	0.39	0.30
Feb-93	1.91	1.66	0.19	4.08	0.09	0.39	0.30
Mar-93	1.91	1.66	0.19	4.08	0.09	0.39	0.30
Apr-93	1.91	1.66	0.19	4.08	0.12	0.55	0.42
May-93	1.91	1.66	0.19	4.08	0.12	0.55	0.42
Jun-93	1.91	1.66	0.19	4.08	0.17	0.76	0.57
Jul-93	1.91	1.66	0.19	4.08	0.17	0.76	0.57
Aug-93	1.91	1.66	0.19	4.08	0.17	0.76	0.57
Sep-93	1.91	1.66	0.19	4.08	0.17	0.76	0.57
Oct-93	1.91	1.66	0.19	4.08	0.12	0.55	0.42
Nov-93	1.91	1.66	0.19	4.08	0.12	0.55	0.42
Dec-93	1.91	1.66	0.19	4.08	0.09	0.39	0.30
Jan-94	1.93	1.68	0.19	4.12	0.09	0.40	0.30
Feb-94	1.93	1.68	0.19	4.12	0.09	0.40	0.30
Mar-94	1.93	1.68	0.19	4.12	0.09	0.40	0.30
Apr-94	1.93	1.68	0.19	4.12	0.12	0.56	0.42
May-94	1.93	1.68	0.19	4.12	0.12	0.56	0.42
Jun-94	1.93	1.68	0.19	4.12	0.17	0.77	0.58
Jul-94	1.93	1.68	0.19	4.12	0.17	0.77	0.58
Aug-94	1.93	1.68	0.19	4.12	0.17	0.77	0.58
Sep-94	1.93	1.68	0.19	4.12	0.17	0.77	0.58
Oct-94	1.93	1.68	0.19	4.12	0.12	0.56	0.42
Nov-94	1.93	1.68	0.19	4.12	0.12	0.56	0.42
Dec-94	1.93	1.68	0.19	4.12	0.09	0.40	0.30
Jan-95	1.94	1.70	0.20	4.16	0.09	0.40	0.30
Feb-95	1.94	1.70	0.20	4.16	0.09	0.40	0.30
Mar-95	1.94	1.70	0.20	4.16	0.09	0.40	0.30
Apr-95	1.94	1.70	0.20	4.16	0.12	0.56	0.42
May-95	1.94	1.70	0.20	4.16	0.12	0.56	0.42
Jun-95	1.94	1.70	0.20	4.16	0.17	0.78	0.59
Jul-95	1.94	1.70	0.20	4.16	0.17	0.78	0.59
Aug-95	1.94	1.70	0.20	4.16	0.17	0.78	0.59
Sep-95	1.94	1.70	0.20	4.16	0.17	0.78	0.59
Oct-95	1.94	1.70	0.20	4.16	0.12	0.56	0.42
Nov-95	1.94	1.70	0.20	4.16	0.12	0.56	0.42
Dec-95	1.94	1.70	0.20	4.16	0.09	0.40	0.30
Jan-96	1.96	1.71	0.20	4.20	0.09	0.41	0.31
Feb-96	1.96	1.71	0.20	4.20	0.09	0.41	0.31
Mar-96	1.96	1.71	0.20	4.20	0.09	0.41	0.31
Apr-96	1.96	1.71	0.20	4.20	0.12	0.57	0.43
May-96	1.96	1.71	0.20	4.20	0.12	0.57	0.43
Jun-96	1.96	1.71	0.20	4.20	0.17	0.78	0.59
Jul-96	1.96	1.71	0.20	4.20	0.17	0.78	0.59
Aug-96	1.96	1.71	0.20	4.20	0.17	0.78	0.59
Sep-96	1.96	1.71	0.20	4.20	0.17	0.78	0.59
Oct-96	1.96	1.71	0.20	4.20	0.12	0.57	0.43

Average water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Nov-96	1.96	1.71	0.20	4.20	0.12	0.57	0.43
Dec-96	1.96	1.71	0.20	4.20	0.09	0.41	0.31
Jan-97	1.98	1.73	0.20	4.25	0.09	0.41	0.31
Feb-97	1.98	1.73	0.20	4.25	0.09	0.41	0.31
Mar-97	1.98	1.73	0.20	4.25	0.09	0.41	0.31
Apr-97	1.98	1.73	0.20	4.25	0.13	0.57	0.43
May-97	1.98	1.73	0.20	4.25	0.13	0.57	0.43
Jun-97	1.98	1.73	0.20	4.25	0.17	0.79	0.60
Jul-97	1.98	1.73	0.20	4.25	0.17	0.79	0.60
Aug-97	1.98	1.73	0.20	4.25	0.17	0.79	0.60
Sep-97	1.98	1.73	0.20	4.25	0.17	0.79	0.60
Oct-97	1.98	1.73	0.20	4.25	0.13	0.57	0.43
Nov-97	1.98	1.73	0.20	4.25	0.13	0.57	0.43
Dec-97	1.98	1.73	0.20	4.25	0.09	0.41	0.31
Jan-98	2.00	1.75	0.20	4.29	0.09	0.41	0.31
Feb-98	2.00	1.75	0.20	4.29	0.09	0.41	0.31
Mar-98	2.00	1.75	0.20	4.29	0.09	0.41	0.31
Apr-98	2.00	1.75	0.20	4.29	0.13	0.58	0.44
May-98	2.00	1.75	0.20	4.29	0.13	0.58	0.44
Jun-98	2.00	1.75	0.20	4.29	0.18	0.80	0.60
Jul-98	2.00	1.75	0.20	4.29	0.18	0.80	0.60
Aug-98	2.00	1.75	0.20	4.29	0.18	0.80	0.60
Sep-98	2.00	1.75	0.20	4.29	0.18	0.80	0.60
Oct-98	2.00	1.75	0.20	4.29	0.13	0.58	0.44
Nov-98	2.00	1.75	0.20	4.29	0.13	0.58	0.44
Dec-98	2.00	1.75	0.20	4.29	0.09	0.41	0.31

Low water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.31	1.30	0.03	3.19	0.04	0.22	0.02
Feb-86	1.31	1.30	0.03	3.19	0.04	0.22	0.02
Mar-86	1.31	1.30	0.03	3.19	0.04	0.22	0.02
Apr-86	1.31	1.30	0.03	3.19	0.05	0.30	0.02
May-86	1.31	1.30	0.03	3.19	0.05	0.30	0.02
Jun-86	1.31	1.30	0.03	3.19	0.07	0.42	0.03
Jul-86	1.31	1.30	0.03	3.19	0.07	0.42	0.03
Aug-86	1.31	1.30	0.03	3.19	0.07	0.42	0.03
Sep-86	1.31	1.30	0.03	3.19	0.07	0.42	0.03
Oct-86	1.31	1.30	0.03	3.19	0.05	0.30	0.02
Nov-86	1.31	1.30	0.03	3.19	0.05	0.30	0.02
Dec-86	1.31	1.30	0.03	3.19	0.04	0.22	0.02
Jan-87	1.39	1.38	0.03	3.38	0.04	0.23	0.02
Feb-87	1.39	1.38	0.03	3.38	0.04	0.23	0.02
Mar-87	1.39	1.38	0.03	3.38	0.04	0.23	0.02
Apr-87	1.39	1.38	0.03	3.38	0.06	0.32	0.02
May-87	1.39	1.38	0.03	3.38	0.06	0.32	0.02
Jun-87	1.39	1.38	0.03	3.38	0.08	0.45	0.03
Jul-87	1.39	1.38	0.03	3.38	0.08	0.45	0.03
Aug-87	1.39	1.38	0.03	3.38	0.08	0.45	0.03
Sep-87	1.39	1.38	0.03	3.38	0.08	0.45	0.03
Oct-87	1.39	1.38	0.03	3.38	0.06	0.32	0.02
Nov-87	1.39	1.38	0.03	3.38	0.06	0.32	0.02

Low water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Dec-87	1.39	1.38	0.03	3.38	0.04	0.23	0.02
Jan-88	1.47	1.46	0.03	3.58	0.04	0.24	0.02
Feb-88	1.47	1.46	0.03	3.58	0.04	0.24	0.02
Mar-88	1.47	1.46	0.03	3.58	0.04	0.24	0.02
Apr-88	1.47	1.46	0.03	3.58	0.06	0.34	0.02
May-88	1.47	1.46	0.03	3.58	0.06	0.34	0.02
Jun-88	1.47	1.46	0.03	3.58	0.08	0.47	0.03
Jul-88	1.47	1.46	0.03	3.58	0.08	0.47	0.03
Aug-88	1.47	1.46	0.03	3.58	0.08	0.47	0.03
Sep-88	1.47	1.46	0.03	3.58	0.08	0.47	0.03
Oct-88	1.47	1.46	0.03	3.58	0.06	0.34	0.02
Nov-88	1.47	1.46	0.03	3.58	0.06	0.34	0.02
Dec-88	1.47	1.46	0.03	3.58	0.04	0.24	0.02
Jan-89	1.56	1.55	0.04	3.80	0.04	0.26	0.02
Feb-89	1.56	1.55	0.04	3.80	0.04	0.26	0.02
Mar-89	1.56	1.55	0.04	3.80	0.04	0.26	0.02
Apr-89	1.56	1.55	0.04	3.80	0.06	0.36	0.03
May-89	1.56	1.55	0.04	3.80	0.06	0.36	0.03
Jun-89	1.56	1.55	0.04	3.80	0.09	0.50	0.03
Jul-89	1.56	1.55	0.04	3.80	0.09	0.50	0.03
Aug-89	1.56	1.55	0.04	3.80	0.09	0.50	0.03
Sep-89	1.56	1.55	0.04	3.80	0.09	0.50	0.03
Oct-89	1.56	1.55	0.04	3.80	0.06	0.36	0.03
Nov-89	1.56	1.55	0.04	3.80	0.06	0.36	0.03
Dec-89	1.56	1.55	0.04	3.80	0.04	0.26	0.02
Jan-90	1.58	1.57	0.04	3.85	0.05	0.26	0.02
Feb-90	1.58	1.57	0.04	3.85	0.05	0.26	0.02
Mar-90	1.58	1.57	0.04	3.85	0.05	0.26	0.02
Apr-90	1.58	1.57	0.04	3.85	0.06	0.37	0.03
May-90	1.58	1.57	0.04	3.85	0.06	0.37	0.03
Jun-90	1.58	1.57	0.04	3.85	0.09	0.51	0.03
Jul-90	1.58	1.57	0.04	3.85	0.09	0.51	0.03
Aug-90	1.58	1.57	0.04	3.85	0.09	0.51	0.03
Sep-90	1.58	1.57	0.04	3.85	0.09	0.51	0.03
Oct-90	1.58	1.57	0.04	3.85	0.06	0.37	0.03
Nov-90	1.58	1.57	0.04	3.85	0.06	0.37	0.03
Dec-90	1.58	1.57	0.04	3.85	0.05	0.26	0.02
Jan-91	1.60	1.59	0.04	3.90	0.05	0.27	0.02
Feb-91	1.60	1.59	0.04	3.90	0.05	0.27	0.02
Mar-91	1.60	1.59	0.04	3.90	0.05	0.27	0.02
Apr-91	1.60	1.59	0.04	3.90	0.06	0.37	0.03
May-91	1.60	1.59	0.04	3.90	0.06	0.37	0.03
Jun-91	1.60	1.59	0.04	3.90	0.09	0.51	0.04
Jul-91	1.60	1.59	0.04	3.90	0.09	0.51	0.04
Aug-91	1.60	1.59	0.04	3.90	0.09	0.51	0.04
Sep-91	1.60	1.59	0.04	3.90	0.09	0.51	0.04
Oct-91	1.60	1.59	0.04	3.90	0.06	0.37	0.03
Nov-91	1.60	1.59	0.04	3.90	0.06	0.37	0.03
Dec-91	1.60	1.59	0.04	3.90	0.05	0.27	0.02
Jan-92	1.62	1.61	0.04	3.95	0.05	0.27	0.02
Feb-92	1.62	1.61	0.04	3.95	0.05	0.27	0.02
Mar-92	1.62	1.61	0.04	3.95	0.05	0.27	0.02

Low water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Apr-92	1.62	1.61	0.04	3.95	0.06	0.38	0.03
May-92	1.62	1.61	0.04	3.95	0.06	0.38	0.03
Jun-92	1.62	1.61	0.04	3.95	0.09	0.52	0.04
Jul-92	1.62	1.61	0.04	3.95	0.09	0.52	0.04
Aug-92	1.62	1.61	0.04	3.95	0.09	0.52	0.04
Sep-92	1.62	1.61	0.04	3.95	0.09	0.52	0.04
Oct-92	1.62	1.61	0.04	3.95	0.06	0.38	0.03
Nov-92	1.62	1.61	0.04	3.95	0.06	0.38	0.03
Dec-92	1.62	1.61	0.04	3.95	0.05	0.27	0.02
Jan-93	1.64	1.63	0.04	4.00	0.05	0.27	0.02
Feb-93	1.64	1.63	0.04	4.00	0.05	0.27	0.02
Mar-93	1.64	1.63	0.04	4.00	0.05	0.27	0.02
Apr-93	1.64	1.63	0.04	4.00	0.07	0.38	0.03
May-93	1.64	1.63	0.04	4.00	0.07	0.38	0.03
Jun-93	1.64	1.63	0.04	4.00	0.09	0.53	0.04
Jul-93	1.64	1.63	0.04	4.00	0.09	0.53	0.04
Aug-93	1.64	1.63	0.04	4.00	0.09	0.53	0.04
Sep-93	1.64	1.63	0.04	4.00	0.09	0.53	0.04
Oct-93	1.64	1.63	0.04	4.00	0.07	0.38	0.03
Nov-93	1.64	1.63	0.04	4.00	0.07	0.38	0.03
Dec-93	1.64	1.63	0.04	4.00	0.05	0.27	0.02
Jan-94	1.66	1.65	0.04	4.05	0.05	0.28	0.02
Feb-94	1.66	1.65	0.04	4.05	0.05	0.28	0.02
Mar-94	1.66	1.65	0.04	4.05	0.05	0.28	0.02
Apr-94	1.66	1.65	0.04	4.05	0.07	0.39	0.03
May-94	1.66	1.65	0.04	4.05	0.07	0.39	0.03
Jun-94	1.66	1.65	0.04	4.05	0.09	0.53	0.04
Jul-94	1.66	1.65	0.04	4.05	0.09	0.53	0.04
Aug-94	1.66	1.65	0.04	4.05	0.09	0.53	0.04
Sep-94	1.66	1.65	0.04	4.05	0.09	0.53	0.04
Oct-94	1.66	1.65	0.04	4.05	0.07	0.39	0.03
Nov-94	1.66	1.65	0.04	4.05	0.07	0.39	0.03
Dec-94	1.66	1.65	0.04	4.05	0.05	0.28	0.02
Jan-95	1.69	1.67	0.04	4.11	0.05	0.28	0.02
Feb-95	1.69	1.67	0.04	4.11	0.05	0.28	0.02
Mar-95	1.69	1.67	0.04	4.11	0.05	0.28	0.02
Apr-95	1.69	1.67	0.04	4.11	0.07	0.39	0.03
May-95	1.69	1.67	0.04	4.11	0.07	0.39	0.03
Jun-95	1.69	1.67	0.04	4.11	0.09	0.54	0.04
Jul-95	1.69	1.67	0.04	4.11	0.09	0.54	0.04
Aug-95	1.69	1.67	0.04	4.11	0.09	0.54	0.04
Sep-95	1.69	1.67	0.04	4.11	0.09	0.54	0.04
Oct-95	1.69	1.67	0.04	4.11	0.07	0.39	0.03
Nov-95	1.69	1.67	0.04	4.11	0.07	0.39	0.03
Dec-95	1.69	1.67	0.04	4.11	0.05	0.28	0.02
Jan-96	1.71	1.69	0.04	4.16	0.05	0.28	0.02
Feb-96	1.71	1.69	0.04	4.16	0.05	0.28	0.02
Mar-96	1.71	1.69	0.04	4.16	0.05	0.28	0.02
Apr-96	1.71	1.69	0.04	4.16	0.07	0.40	0.03
May-96	1.71	1.69	0.04	4.16	0.07	0.40	0.03
Jun-96	1.71	1.69	0.04	4.16	0.09	0.55	0.04
Jul-96	1.71	1.69	0.04	4.16	0.09	0.55	0.04

Low water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Aug-96	1.71	1.69	0.04	4.16	0.09	0.55	0.04
Sep-96	1.71	1.69	0.04	4.16	0.09	0.55	0.04
Oct-96	1.71	1.69	0.04	4.16	0.07	0.40	0.03
Nov-96	1.71	1.69	0.04	4.16	0.07	0.40	0.03
Dec-96	1.71	1.69	0.04	4.16	0.05	0.28	0.02
Jan-97	1.73	1.72	0.04	4.21	0.05	0.29	0.02
Feb-97	1.73	1.72	0.04	4.21	0.05	0.29	0.02
Mar-97	1.73	1.72	0.04	4.21	0.05	0.29	0.02
Apr-97	1.73	1.72	0.04	4.21	0.07	0.40	0.03
May-97	1.73	1.72	0.04	4.21	0.07	0.40	0.03
Jun-97	1.73	1.72	0.04	4.21	0.10	0.56	0.04
Jul-97	1.73	1.72	0.04	4.21	0.10	0.56	0.04
Aug-97	1.73	1.72	0.04	4.21	0.10	0.56	0.04
Sep-97	1.73	1.72	0.04	4.21	0.10	0.56	0.04
Oct-97	1.73	1.72	0.04	4.21	0.07	0.40	0.03
Nov-97	1.73	1.72	0.04	4.21	0.07	0.40	0.03
Dec-97	1.73	1.72	0.04	4.21	0.05	0.29	0.02
Jan-98	1.75	1.74	0.04	4.27	0.05	0.29	0.02
Feb-98	1.75	1.74	0.04	4.27	0.05	0.29	0.02
Mar-98	1.75	1.74	0.04	4.27	0.05	0.29	0.02
Apr-98	1.75	1.74	0.04	4.27	0.07	0.41	0.03
May-98	1.75	1.74	0.04	4.27	0.07	0.41	0.03
Jun-98	1.75	1.74	0.04	4.27	0.10	0.56	0.04
Jul-98	1.75	1.74	0.04	4.27	0.10	0.56	0.04
Aug-98	1.75	1.74	0.04	4.27	0.10	0.56	0.04
Sep-98	1.75	1.74	0.04	4.27	0.10	0.56	0.04
Oct-98	1.75	1.74	0.04	4.27	0.07	0.41	0.03
Nov-98	1.75	1.74	0.04	4.27	0.07	0.41	0.03
Dec-98	1.75	1.74	0.04	4.27	0.05	0.29	0.02

High water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.68	1.78	0.15	4.00	0.07	0.35	0.23
Feb-86	1.68	1.78	0.15	4.00	0.07	0.35	0.23
Mar-86	1.68	1.78	0.15	4.00	0.07	0.35	0.23
Apr-86	1.68	1.78	0.15	4.00	0.09	0.49	0.33
May-86	1.68	1.78	0.15	4.00	0.09	0.49	0.33
Jun-86	1.68	1.78	0.15	4.00	0.13	0.68	0.45
Jul-86	1.68	1.78	0.15	4.00	0.13	0.68	0.45
Aug-86	1.68	1.78	0.15	4.00	0.13	0.68	0.45
Sep-86	1.68	1.78	0.15	4.00	0.13	0.68	0.45
Oct-86	1.68	1.78	0.15	4.00	0.09	0.49	0.33
Nov-86	1.68	1.78	0.15	4.00	0.09	0.49	0.33
Dec-86	1.68	1.78	0.15	4.00	0.07	0.35	0.23
Jan-87	1.78	1.89	0.16	4.24	0.07	0.37	0.25
Feb-87	1.78	1.89	0.16	4.24	0.07	0.37	0.25
Mar-87	1.78	1.89	0.16	4.24	0.07	0.37	0.25
Apr-87	1.78	1.89	0.16	4.24	0.10	0.52	0.35
May-87	1.78	1.89	0.16	4.24	0.10	0.52	0.35
Jun-87	1.78	1.89	0.16	4.24	0.14	0.72	0.48
Jul-87	1.78	1.89	0.16	4.24	0.14	0.72	0.48
Aug-87	1.78	1.89	0.16	4.24	0.14	0.72	0.48

High water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Sep-87	1.78	1.89	0.16	4.24	0.14	0.72	0.48
Oct-87	1.78	1.89	0.16	4.24	0.10	0.52	0.35
Nov-87	1.78	1.89	0.16	4.24	0.10	0.52	0.35
Dec-87	1.78	1.89	0.16	4.24	0.07	0.37	0.25
Jan-88	1.89	2.00	0.17	4.49	0.08	0.40	0.26
Feb-88	1.89	2.00	0.17	4.49	0.08	0.40	0.26
Mar-88	1.89	2.00	0.17	4.49	0.08	0.40	0.26
Apr-88	1.89	2.00	0.17	4.49	0.11	0.55	0.37
May-88	1.89	2.00	0.17	4.49	0.11	0.55	0.37
Jun-88	1.89	2.00	0.17	4.49	0.15	0.77	0.51
Jul-88	1.89	2.00	0.17	4.49	0.15	0.77	0.51
Aug-88	1.89	2.00	0.17	4.49	0.15	0.77	0.51
Sep-88	1.89	2.00	0.17	4.49	0.15	0.77	0.51
Oct-88	1.89	2.00	0.17	4.49	0.11	0.55	0.37
Nov-88	1.89	2.00	0.17	4.49	0.11	0.55	0.37
Dec-88	1.89	2.00	0.17	4.49	0.08	0.40	0.26
Jan-89	2.00	2.12	0.18	4.76	0.08	0.42	0.28
Feb-89	2.00	2.12	0.18	4.76	0.08	0.42	0.28
Mar-89	2.00	2.12	0.18	4.76	0.08	0.42	0.28
Apr-89	2.00	2.12	0.18	4.76	0.11	0.59	0.39
May-89	2.00	2.12	0.18	4.76	0.11	0.59	0.39
Jun-89	2.00	2.12	0.18	4.76	0.16	0.81	0.54
Jul-89	2.00	2.12	0.18	4.76	0.16	0.81	0.54
Aug-89	2.00	2.12	0.18	4.76	0.16	0.81	0.54
Sep-89	2.00	2.12	0.18	4.76	0.16	0.81	0.54
Oct-89	2.00	2.12	0.18	4.76	0.11	0.59	0.39
Nov-89	2.00	2.12	0.18	4.76	0.11	0.59	0.39
Dec-89	2.00	2.12	0.18	4.76	0.08	0.42	0.28
Jan-90	2.03	2.15	0.18	4.83	0.08	0.43	0.28
Feb-90	2.03	2.15	0.18	4.83	0.08	0.43	0.28
Mar-90	2.03	2.15	0.18	4.83	0.08	0.43	0.28
Apr-90	2.03	2.15	0.18	4.83	0.11	0.60	0.39
May-90	2.03	2.15	0.18	4.83	0.11	0.60	0.39
Jun-90	2.03	2.15	0.18	4.83	0.16	0.82	0.54
Jul-90	2.03	2.15	0.18	4.83	0.16	0.82	0.54
Aug-90	2.03	2.15	0.18	4.83	0.16	0.82	0.54
Sep-90	2.03	2.15	0.18	4.83	0.16	0.82	0.54
Oct-90	2.03	2.15	0.18	4.83	0.11	0.60	0.39
Nov-90	2.03	2.15	0.18	4.83	0.11	0.60	0.39
Dec-90	2.03	2.15	0.18	4.83	0.08	0.43	0.28
Jan-91	2.05	2.18	0.18	4.89	0.08	0.43	0.28
Feb-91	2.05	2.18	0.18	4.89	0.08	0.43	0.28
Mar-91	2.05	2.18	0.18	4.89	0.08	0.43	0.28
Apr-91	2.05	2.18	0.18	4.89	0.12	0.60	0.40
May-91	2.05	2.18	0.18	4.89	0.12	0.60	0.40
Jun-91	2.05	2.18	0.18	4.89	0.16	0.83	0.55
Jul-91	2.05	2.18	0.18	4.89	0.16	0.83	0.55
Aug-91	2.05	2.18	0.18	4.89	0.16	0.83	0.55
Sep-91	2.05	2.18	0.18	4.89	0.16	0.83	0.55
Oct-91	2.05	2.18	0.18	4.89	0.12	0.60	0.40
Nov-91	2.05	2.18	0.18	4.89	0.12	0.60	0.40
Dec-91	2.05	2.18	0.18	4.89	0.08	0.43	0.28

High water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-92	2.08	2.20	0.19	4.95	0.08	0.44	0.29
Feb-92	2.08	2.20	0.19	4.95	0.08	0.44	0.29
Mar-92	2.08	2.20	0.19	4.95	0.08	0.44	0.29
Apr-92	2.08	2.20	0.19	4.95	0.12	0.61	0.40
May-92	2.08	2.20	0.19	4.95	0.12	0.61	0.40
Jun-92	2.08	2.20	0.19	4.95	0.16	0.84	0.56
Jul-92	2.08	2.20	0.19	4.95	0.16	0.84	0.56
Aug-92	2.08	2.20	0.19	4.95	0.16	0.84	0.56
Sep-92	2.08	2.20	0.19	4.95	0.16	0.84	0.56
Oct-92	2.08	2.20	0.19	4.95	0.12	0.61	0.40
Nov-92	2.08	2.20	0.19	4.95	0.12	0.61	0.40
Dec-92	2.08	2.20	0.19	4.95	0.08	0.44	0.29
Jan-93	2.11	2.23	0.19	5.02	0.08	0.44	0.29
Feb-93	2.11	2.23	0.19	5.02	0.08	0.44	0.29
Mar-93	2.11	2.23	0.19	5.02	0.08	0.44	0.29
Apr-93	2.11	2.23	0.19	5.02	0.12	0.62	0.41
May-93	2.11	2.23	0.19	5.02	0.12	0.62	0.41
Jun-93	2.11	2.23	0.19	5.02	0.16	0.85	0.56
Jul-93	2.11	2.23	0.19	5.02	0.16	0.85	0.56
Aug-93	2.11	2.23	0.19	5.02	0.16	0.85	0.56
Sep-93	2.11	2.23	0.19	5.02	0.16	0.85	0.56
Oct-93	2.11	2.23	0.19	5.02	0.12	0.62	0.41
Nov-93	2.11	2.23	0.19	5.02	0.12	0.62	0.41
Dec-93	2.11	2.23	0.19	5.02	0.08	0.44	0.29
Jan-94	2.13	2.26	0.19	5.08	0.09	0.45	0.30
Feb-94	2.13	2.26	0.19	5.08	0.09	0.45	0.30
Mar-94	2.13	2.26	0.19	5.08	0.09	0.45	0.30
Apr-94	2.13	2.26	0.19	5.08	0.12	0.63	0.41
May-94	2.13	2.26	0.19	5.08	0.12	0.63	0.41
Jun-94	2.13	2.26	0.19	5.08	0.17	0.87	0.57
Jul-94	2.13	2.26	0.19	5.08	0.17	0.87	0.57
Aug-94	2.13	2.26	0.19	5.08	0.17	0.87	0.57
Sep-94	2.13	2.26	0.19	5.08	0.17	0.87	0.57
Oct-94	2.13	2.26	0.19	5.08	0.12	0.63	0.41
Nov-94	2.13	2.26	0.19	5.08	0.12	0.63	0.41
Dec-94	2.13	2.26	0.19	5.08	0.09	0.45	0.30
Jan-95	2.16	2.29	0.19	5.15	0.09	0.45	0.30
Feb-95	2.16	2.29	0.19	5.15	0.09	0.45	0.30
Mar-95	2.16	2.29	0.19	5.15	0.09	0.45	0.30
Apr-95	2.16	2.29	0.19	5.15	0.12	0.64	0.42
May-95	2.16	2.29	0.19	5.15	0.12	0.64	0.42
Jun-95	2.16	2.29	0.19	5.15	0.17	0.88	0.58
Jul-95	2.16	2.29	0.19	5.15	0.17	0.88	0.58
Aug-95	2.16	2.29	0.19	5.15	0.17	0.88	0.58
Sep-95	2.16	2.29	0.19	5.15	0.17	0.88	0.58
Oct-95	2.16	2.29	0.19	5.15	0.12	0.64	0.42
Nov-95	2.16	2.29	0.19	5.15	0.12	0.64	0.42
Dec-95	2.16	2.29	0.19	5.15	0.09	0.45	0.30
Jan-96	2.19	2.32	0.20	5.21	0.09	0.46	0.30
Feb-96	2.19	2.32	0.20	5.21	0.09	0.46	0.30
Mar-96	2.19	2.32	0.20	5.21	0.09	0.46	0.30
Apr-96	2.19	2.32	0.20	5.21	0.12	0.64	0.42

High water user - Low water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
May-96	2.19	2.32	0.20	5.21	0.12	0.64	0.42
Jun-96	2.19	2.32	0.20	5.21	0.17	0.89	0.59
Jul-96	2.19	2.32	0.20	5.21	0.17	0.89	0.59
Aug-96	2.19	2.32	0.20	5.21	0.17	0.89	0.59
Sep-96	2.19	2.32	0.20	5.21	0.17	0.89	0.59
Oct-96	2.19	2.32	0.20	5.21	0.12	0.64	0.42
Nov-96	2.19	2.32	0.20	5.21	0.12	0.64	0.42
Dec-96	2.19	2.32	0.20	5.21	0.09	0.46	0.30
Jan-97	2.22	2.35	0.20	5.28	0.09	0.47	0.31
Feb-97	2.22	2.35	0.20	5.28	0.09	0.47	0.31
Mar-97	2.22	2.35	0.20	5.28	0.09	0.47	0.31
Apr-97	2.22	2.35	0.20	5.28	0.12	0.65	0.43
May-97	2.22	2.35	0.20	5.28	0.12	0.65	0.43
Jun-97	2.22	2.35	0.20	5.28	0.17	0.90	0.59
Jul-97	2.22	2.35	0.20	5.28	0.17	0.90	0.59
Aug-97	2.22	2.35	0.20	5.28	0.17	0.90	0.59
Sep-97	2.22	2.35	0.20	5.28	0.17	0.90	0.59
Oct-97	2.22	2.35	0.20	5.28	0.12	0.65	0.43
Nov-97	2.22	2.35	0.20	5.28	0.12	0.65	0.43
Dec-97	2.22	2.35	0.20	5.28	0.09	0.47	0.31
Jan-98	2.25	2.38	0.20	5.35	0.09	0.47	0.31
Feb-98	2.25	2.38	0.20	5.35	0.09	0.47	0.31
Mar-98	2.25	2.38	0.20	5.35	0.09	0.47	0.31
Apr-98	2.25	2.38	0.20	5.35	0.13	0.66	0.44
May-98	2.25	2.38	0.20	5.35	0.13	0.66	0.44
Jun-98	2.25	2.38	0.20	5.35	0.17	0.91	0.60
Jul-98	2.25	2.38	0.20	5.35	0.17	0.91	0.60
Aug-98	2.25	2.38	0.20	5.35	0.17	0.91	0.60
Sep-98	2.25	2.38	0.20	5.35	0.17	0.91	0.60
Oct-98	2.25	2.38	0.20	5.35	0.13	0.66	0.44
Nov-98	2.25	2.38	0.20	5.35	0.13	0.66	0.44
Dec-98	2.25	2.38	0.20	5.35	0.09	0.47	0.31

Average water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.26	1.00	0.15	2.64	0.07	0.26	0.07
Feb-86	1.26	1.00	0.15	2.64	0.07	0.26	0.07
Mar-86	1.26	1.00	0.15	2.64	0.07	0.26	0.07
Apr-86	1.26	1.00	0.15	2.64	0.09	0.36	0.09
May-86	1.26	1.00	0.15	2.64	0.09	0.36	0.09
Jun-86	1.26	1.00	0.15	2.64	0.13	0.49	0.13
Jul-86	1.26	1.00	0.15	2.64	0.13	0.49	0.13
Aug-86	1.26	1.00	0.15	2.64	0.13	0.49	0.13
Sep-86	1.26	1.00	0.15	2.64	0.13	0.49	0.13
Oct-86	1.26	1.00	0.15	2.64	0.09	0.36	0.09
Nov-86	1.26	1.00	0.15	2.64	0.09	0.36	0.09
Dec-86	1.26	1.00	0.15	2.64	0.07	0.26	0.07
Jan-87	1.34	1.06	0.16	2.80	0.07	0.27	0.07
Feb-87	1.34	1.06	0.16	2.80	0.07	0.27	0.07
Mar-87	1.34	1.06	0.16	2.80	0.07	0.27	0.07
Apr-87	1.34	1.06	0.16	2.80	0.10	0.38	0.10

Average water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
May-87	1.34	1.06	0.16	2.80	0.10	0.38	0.10
Jun-87	1.34	1.06	0.16	2.80	0.14	0.52	0.14
Jul-87	1.34	1.06	0.16	2.80	0.14	0.52	0.14
Aug-87	1.34	1.06	0.16	2.80	0.14	0.52	0.14
Sep-87	1.34	1.06	0.16	2.80	0.14	0.52	0.14
Oct-87	1.34	1.06	0.16	2.80	0.10	0.38	0.10
Nov-87	1.34	1.06	0.16	2.80	0.10	0.38	0.10
Dec-87	1.34	1.06	0.16	2.80	0.07	0.27	0.07
Jan-88	1.41	1.12	0.17	2.96	0.08	0.29	0.08
Feb-88	1.41	1.12	0.17	2.96	0.08	0.29	0.08
Mar-88	1.41	1.12	0.17	2.96	0.08	0.29	0.08
Apr-88	1.41	1.12	0.17	2.96	0.11	0.40	0.11
May-88	1.41	1.12	0.17	2.96	0.11	0.40	0.11
Jun-88	1.41	1.12	0.17	2.96	0.15	0.55	0.15
Jul-88	1.41	1.12	0.17	2.96	0.15	0.55	0.15
Aug-88	1.41	1.12	0.17	2.96	0.15	0.55	0.15
Sep-88	1.41	1.12	0.17	2.96	0.15	0.55	0.15
Oct-88	1.41	1.12	0.17	2.96	0.11	0.40	0.11
Nov-88	1.41	1.12	0.17	2.96	0.11	0.40	0.11
Dec-88	1.41	1.12	0.17	2.96	0.08	0.29	0.08
Jan-89	1.49	1.18	0.18	3.12	0.08	0.30	0.08
Feb-89	1.49	1.18	0.18	3.12	0.08	0.30	0.08
Mar-89	1.49	1.18	0.18	3.12	0.08	0.30	0.08
Apr-89	1.49	1.18	0.18	3.12	0.11	0.42	0.11
May-89	1.49	1.18	0.18	3.12	0.11	0.42	0.11
Jun-89	1.49	1.18	0.18	3.12	0.15	0.58	0.15
Jul-89	1.49	1.18	0.18	3.12	0.15	0.58	0.15
Aug-89	1.49	1.18	0.18	3.12	0.15	0.58	0.15
Sep-89	1.49	1.18	0.18	3.12	0.15	0.58	0.15
Oct-89	1.49	1.18	0.18	3.12	0.11	0.42	0.11
Nov-89	1.49	1.18	0.18	3.12	0.11	0.42	0.11
Dec-89	1.49	1.18	0.18	3.12	0.08	0.30	0.08
Jan-90	1.56	1.24	0.19	3.27	0.08	0.32	0.08
Feb-90	1.56	1.24	0.19	3.27	0.08	0.32	0.08
Mar-90	1.56	1.24	0.19	3.27	0.08	0.32	0.08
Apr-90	1.56	1.24	0.19	3.27	0.12	0.44	0.12
May-90	1.56	1.24	0.19	3.27	0.12	0.44	0.12
Jun-90	1.56	1.24	0.19	3.27	0.16	0.61	0.16
Jul-90	1.56	1.24	0.19	3.27	0.16	0.61	0.16
Aug-90	1.56	1.24	0.19	3.27	0.16	0.61	0.16
Sep-90	1.56	1.24	0.19	3.27	0.16	0.61	0.16
Oct-90	1.56	1.24	0.19	3.27	0.12	0.44	0.12
Nov-90	1.56	1.24	0.19	3.27	0.12	0.44	0.12
Dec-90	1.56	1.24	0.19	3.27	0.08	0.32	0.08
Jan-91	1.58	1.25	0.19	3.31	0.08	0.32	0.08
Feb-91	1.58	1.25	0.19	3.31	0.08	0.32	0.08
Mar-91	1.58	1.25	0.19	3.31	0.08	0.32	0.08
Apr-91	1.58	1.25	0.19	3.31	0.12	0.45	0.12
May-91	1.58	1.25	0.19	3.31	0.12	0.45	0.12
Jun-91	1.58	1.25	0.19	3.31	0.16	0.62	0.16
Jul-91	1.58	1.25	0.19	3.31	0.16	0.62	0.16
Aug-91	1.58	1.25	0.19	3.31	0.16	0.62	0.16

Average water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Sep-91	1.58	1.25	0.19	3.31	0.16	0.62	0.16
Oct-91	1.58	1.25	0.19	3.31	0.12	0.45	0.12
Nov-91	1.58	1.25	0.19	3.31	0.12	0.45	0.12
Dec-91	1.58	1.25	0.19	3.31	0.08	0.32	0.08
Jan-92	1.60	1.27	0.19	3.34	0.09	0.32	0.09
Feb-92	1.60	1.27	0.19	3.34	0.09	0.32	0.09
Mar-92	1.60	1.27	0.19	3.34	0.09	0.32	0.09
Apr-92	1.60	1.27	0.19	3.34	0.12	0.45	0.12
May-92	1.60	1.27	0.19	3.34	0.12	0.45	0.12
Jun-92	1.60	1.27	0.19	3.34	0.17	0.62	0.17
Jul-92	1.60	1.27	0.19	3.34	0.17	0.62	0.17
Aug-92	1.60	1.27	0.19	3.34	0.17	0.62	0.17
Sep-92	1.60	1.27	0.19	3.34	0.17	0.62	0.17
Oct-92	1.60	1.27	0.19	3.34	0.12	0.45	0.12
Nov-92	1.60	1.27	0.19	3.34	0.12	0.45	0.12
Dec-92	1.60	1.27	0.19	3.34	0.09	0.32	0.09
Jan-93	1.61	1.28	0.19	3.38	0.09	0.33	0.09
Feb-93	1.61	1.28	0.19	3.38	0.09	0.33	0.09
Mar-93	1.61	1.28	0.19	3.38	0.09	0.33	0.09
Apr-93	1.61	1.28	0.19	3.38	0.12	0.46	0.12
May-93	1.61	1.28	0.19	3.38	0.12	0.46	0.12
Jun-93	1.61	1.28	0.19	3.38	0.17	0.63	0.17
Jul-93	1.61	1.28	0.19	3.38	0.17	0.63	0.17
Aug-93	1.61	1.28	0.19	3.38	0.17	0.63	0.17
Sep-93	1.61	1.28	0.19	3.38	0.17	0.63	0.17
Oct-93	1.61	1.28	0.19	3.38	0.12	0.46	0.12
Nov-93	1.61	1.28	0.19	3.38	0.12	0.46	0.12
Dec-93	1.61	1.28	0.19	3.38	0.09	0.33	0.09
Jan-94	1.63	1.29	0.19	3.41	0.09	0.33	0.09
Feb-94	1.63	1.29	0.19	3.41	0.09	0.33	0.09
Mar-94	1.63	1.29	0.19	3.41	0.09	0.33	0.09
Apr-94	1.63	1.29	0.19	3.41	0.12	0.46	0.12
May-94	1.63	1.29	0.19	3.41	0.12	0.46	0.12
Jun-94	1.63	1.29	0.19	3.41	0.17	0.64	0.17
Jul-94	1.63	1.29	0.19	3.41	0.17	0.64	0.17
Aug-94	1.63	1.29	0.19	3.41	0.17	0.64	0.17
Sep-94	1.63	1.29	0.19	3.41	0.17	0.64	0.17
Oct-94	1.63	1.29	0.19	3.41	0.12	0.46	0.12
Nov-94	1.63	1.29	0.19	3.41	0.12	0.46	0.12
Dec-94	1.63	1.29	0.19	3.41	0.09	0.33	0.09
Jan-95	1.64	1.31	0.20	3.45	0.09	0.33	0.09
Feb-95	1.64	1.31	0.20	3.45	0.09	0.33	0.09
Mar-95	1.64	1.31	0.20	3.45	0.09	0.33	0.09
Apr-95	1.64	1.31	0.20	3.45	0.12	0.47	0.12
May-95	1.64	1.31	0.20	3.45	0.12	0.47	0.12
Jun-95	1.64	1.31	0.20	3.45	0.17	0.64	0.17
Jul-95	1.64	1.31	0.20	3.45	0.17	0.64	0.17
Aug-95	1.64	1.31	0.20	3.45	0.17	0.64	0.17
Sep-95	1.64	1.31	0.20	3.45	0.17	0.64	0.17
Oct-95	1.64	1.31	0.20	3.45	0.12	0.47	0.12
Nov-95	1.64	1.31	0.20	3.45	0.12	0.47	0.12
Dec-95	1.64	1.31	0.20	3.45	0.09	0.33	0.09

Average water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-96	1.66	1.32	0.20	3.48	0.09	0.34	0.09
Feb-96	1.66	1.32	0.20	3.48	0.09	0.34	0.09
Mar-96	1.66	1.32	0.20	3.48	0.09	0.34	0.09
Apr-96	1.66	1.32	0.20	3.48	0.12	0.47	0.12
May-96	1.66	1.32	0.20	3.48	0.12	0.47	0.12
Jun-96	1.66	1.32	0.20	3.48	0.17	0.65	0.17
Jul-96	1.66	1.32	0.20	3.48	0.17	0.65	0.17
Aug-96	1.66	1.32	0.20	3.48	0.17	0.65	0.17
Sep-96	1.66	1.32	0.20	3.48	0.17	0.65	0.17
Oct-96	1.66	1.32	0.20	3.48	0.12	0.47	0.12
Nov-96	1.66	1.32	0.20	3.48	0.12	0.47	0.12
Dec-96	1.66	1.32	0.20	3.48	0.09	0.34	0.09
Jan-97	1.68	1.33	0.20	3.51	0.09	0.34	0.09
Feb-97	1.68	1.33	0.20	3.51	0.09	0.34	0.09
Mar-97	1.68	1.33	0.20	3.51	0.09	0.34	0.09
Apr-97	1.68	1.33	0.20	3.51	0.13	0.48	0.13
May-97	1.68	1.33	0.20	3.51	0.13	0.48	0.13
Jun-97	1.68	1.33	0.20	3.51	0.17	0.66	0.17
Jul-97	1.68	1.33	0.20	3.51	0.17	0.66	0.17
Aug-97	1.68	1.33	0.20	3.51	0.17	0.66	0.17
Sep-97	1.68	1.33	0.20	3.51	0.17	0.66	0.17
Oct-97	1.68	1.33	0.20	3.51	0.13	0.48	0.13
Nov-97	1.68	1.33	0.20	3.51	0.13	0.48	0.13
Dec-97	1.68	1.33	0.20	3.51	0.09	0.34	0.09
Jan-98	1.69	1.34	0.20	3.55	0.09	0.34	0.09
Feb-98	1.69	1.34	0.20	3.55	0.09	0.34	0.09
Mar-98	1.69	1.34	0.20	3.55	0.09	0.34	0.09
Apr-98	1.69	1.34	0.20	3.55	0.13	0.48	0.13
May-98	1.69	1.34	0.20	3.55	0.13	0.48	0.13
Jun-98	1.69	1.34	0.20	3.55	0.18	0.66	0.18
Jul-98	1.69	1.34	0.20	3.55	0.18	0.66	0.18
Aug-98	1.69	1.34	0.20	3.55	0.18	0.66	0.18
Sep-98	1.69	1.34	0.20	3.55	0.18	0.66	0.18
Oct-98	1.69	1.34	0.20	3.55	0.13	0.48	0.13
Nov-98	1.69	1.34	0.20	3.55	0.13	0.48	0.13
Dec-98	1.69	1.34	0.20	3.55	0.09	0.34	0.09

Low water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.11	1.00	0.03	2.64	0.04	0.18	0.01
Feb-86	1.11	1.00	0.03	2.64	0.04	0.18	0.01
Mar-86	1.11	1.00	0.03	2.64	0.04	0.18	0.01
Apr-86	1.11	1.00	0.03	2.64	0.05	0.25	0.01
May-86	1.11	1.00	0.03	2.64	0.05	0.25	0.01
Jun-86	1.11	1.00	0.03	2.64	0.07	0.35	0.01
Jul-86	1.11	1.00	0.03	2.64	0.07	0.35	0.01
Aug-86	1.11	1.00	0.03	2.64	0.07	0.35	0.01
Sep-86	1.11	1.00	0.03	2.64	0.07	0.35	0.01
Oct-86	1.11	1.00	0.03	2.64	0.05	0.25	0.01
Nov-86	1.11	1.00	0.03	2.64	0.05	0.25	0.01
Dec-86	1.11	1.00	0.03	2.64	0.04	0.18	0.01
Jan-87	1.18	1.06	0.03	2.80	0.04	0.19	0.01

Low water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Feb-87	1.18	1.06	0.03	2.80	0.04	0.19	0.01
Mar-87	1.18	1.06	0.03	2.80	0.04	0.19	0.01
Apr-87	1.18	1.06	0.03	2.80	0.06	0.27	0.01
May-87	1.18	1.06	0.03	2.80	0.06	0.27	0.01
Jun-87	1.18	1.06	0.03	2.80	0.08	0.37	0.02
Jul-87	1.18	1.06	0.03	2.80	0.08	0.37	0.02
Aug-87	1.18	1.06	0.03	2.80	0.08	0.37	0.02
Sep-87	1.18	1.06	0.03	2.80	0.08	0.37	0.02
Oct-87	1.18	1.06	0.03	2.80	0.06	0.27	0.01
Nov-87	1.18	1.06	0.03	2.80	0.06	0.27	0.01
Dec-87	1.18	1.06	0.03	2.80	0.04	0.19	0.01
Jan-88	1.25	1.12	0.03	2.97	0.04	0.20	0.01
Feb-88	1.25	1.12	0.03	2.97	0.04	0.20	0.01
Mar-88	1.25	1.12	0.03	2.97	0.04	0.20	0.01
Apr-88	1.25	1.12	0.03	2.97	0.06	0.28	0.01
May-88	1.25	1.12	0.03	2.97	0.06	0.28	0.01
Jun-88	1.25	1.12	0.03	2.97	0.08	0.39	0.02
Jul-88	1.25	1.12	0.03	2.97	0.08	0.39	0.02
Aug-88	1.25	1.12	0.03	2.97	0.08	0.39	0.02
Sep-88	1.25	1.12	0.03	2.97	0.08	0.39	0.02
Oct-88	1.25	1.12	0.03	2.97	0.06	0.28	0.01
Nov-88	1.25	1.12	0.03	2.97	0.06	0.28	0.01
Dec-88	1.25	1.12	0.03	2.97	0.04	0.20	0.01
Jan-89	1.32	1.19	0.04	3.14	0.04	0.21	0.01
Feb-89	1.32	1.19	0.04	3.14	0.04	0.21	0.01
Mar-89	1.32	1.19	0.04	3.14	0.04	0.21	0.01
Apr-89	1.32	1.19	0.04	3.14	0.06	0.30	0.01
May-89	1.32	1.19	0.04	3.14	0.06	0.30	0.01
Jun-89	1.32	1.19	0.04	3.14	0.09	0.41	0.02
Jul-89	1.32	1.19	0.04	3.14	0.09	0.41	0.02
Aug-89	1.32	1.19	0.04	3.14	0.09	0.41	0.02
Sep-89	1.32	1.19	0.04	3.14	0.09	0.41	0.02
Oct-89	1.32	1.19	0.04	3.14	0.06	0.30	0.01
Nov-89	1.32	1.19	0.04	3.14	0.06	0.30	0.01
Dec-89	1.32	1.19	0.04	3.14	0.04	0.21	0.01
Jan-90	1.34	1.21	0.04	3.19	0.05	0.22	0.01
Feb-90	1.34	1.21	0.04	3.19	0.05	0.22	0.01
Mar-90	1.34	1.21	0.04	3.19	0.05	0.22	0.01
Apr-90	1.34	1.21	0.04	3.19	0.06	0.30	0.01
May-90	1.34	1.21	0.04	3.19	0.06	0.30	0.01
Jun-90	1.34	1.21	0.04	3.19	0.09	0.42	0.02
Jul-90	1.34	1.21	0.04	3.19	0.09	0.42	0.02
Aug-90	1.34	1.21	0.04	3.19	0.09	0.42	0.02
Sep-90	1.34	1.21	0.04	3.19	0.09	0.42	0.02
Oct-90	1.34	1.21	0.04	3.19	0.06	0.30	0.01
Nov-90	1.34	1.21	0.04	3.19	0.06	0.30	0.01
Dec-90	1.34	1.21	0.04	3.19	0.05	0.22	0.01
Jan-91	1.36	1.22	0.04	3.23	0.05	0.22	0.01
Feb-91	1.36	1.22	0.04	3.23	0.05	0.22	0.01
Mar-91	1.36	1.22	0.04	3.23	0.05	0.22	0.01
Apr-91	1.36	1.22	0.04	3.23	0.06	0.31	0.01
May-91	1.36	1.22	0.04	3.23	0.06	0.31	0.01

Low water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jun-91	1.36	1.22	0.04	3.23	0.09	0.43	0.02
Jul-91	1.36	1.22	0.04	3.23	0.09	0.43	0.02
Aug-91	1.36	1.22	0.04	3.23	0.09	0.43	0.02
Sep-91	1.36	1.22	0.04	3.23	0.09	0.43	0.02
Oct-91	1.36	1.22	0.04	3.23	0.06	0.31	0.01
Nov-91	1.36	1.22	0.04	3.23	0.06	0.31	0.01
Dec-91	1.36	1.22	0.04	3.23	0.05	0.22	0.01
Jan-92	1.37	1.24	0.04	3.27	0.05	0.22	0.01
Feb-92	1.37	1.24	0.04	3.27	0.05	0.22	0.01
Mar-92	1.37	1.24	0.04	3.27	0.05	0.22	0.01
Apr-92	1.37	1.24	0.04	3.27	0.06	0.31	0.01
May-92	1.37	1.24	0.04	3.27	0.06	0.31	0.01
Jun-92	1.37	1.24	0.04	3.27	0.09	0.43	0.02
Jul-92	1.37	1.24	0.04	3.27	0.09	0.43	0.02
Aug-92	1.37	1.24	0.04	3.27	0.09	0.43	0.02
Sep-92	1.37	1.24	0.04	3.27	0.09	0.43	0.02
Oct-92	1.37	1.24	0.04	3.27	0.06	0.31	0.01
Nov-92	1.37	1.24	0.04	3.27	0.06	0.31	0.01
Dec-92	1.37	1.24	0.04	3.27	0.05	0.22	0.01
Jan-93	1.39	1.25	0.04	3.31	0.05	0.23	0.01
Feb-93	1.39	1.25	0.04	3.31	0.05	0.23	0.01
Mar-93	1.39	1.25	0.04	3.31	0.05	0.23	0.01
Apr-93	1.39	1.25	0.04	3.31	0.07	0.32	0.01
May-93	1.39	1.25	0.04	3.31	0.07	0.32	0.01
Jun-93	1.39	1.25	0.04	3.31	0.09	0.44	0.02
Jul-93	1.39	1.25	0.04	3.31	0.09	0.44	0.02
Aug-93	1.39	1.25	0.04	3.31	0.09	0.44	0.02
Sep-93	1.39	1.25	0.04	3.31	0.09	0.44	0.02
Oct-93	1.39	1.25	0.04	3.31	0.07	0.32	0.01
Nov-93	1.39	1.25	0.04	3.31	0.07	0.32	0.01
Dec-93	1.39	1.25	0.04	3.31	0.05	0.23	0.01
Jan-94	1.41	1.27	0.04	3.35	0.05	0.23	0.01
Feb-94	1.41	1.27	0.04	3.35	0.05	0.23	0.01
Mar-94	1.41	1.27	0.04	3.35	0.05	0.23	0.01
Apr-94	1.41	1.27	0.04	3.35	0.07	0.32	0.01
May-94	1.41	1.27	0.04	3.35	0.07	0.32	0.01
Jun-94	1.41	1.27	0.04	3.35	0.09	0.44	0.02
Jul-94	1.41	1.27	0.04	3.35	0.09	0.44	0.02
Aug-94	1.41	1.27	0.04	3.35	0.09	0.44	0.02
Sep-94	1.41	1.27	0.04	3.35	0.09	0.44	0.02
Oct-94	1.41	1.27	0.04	3.35	0.07	0.32	0.01
Nov-94	1.41	1.27	0.04	3.35	0.07	0.32	0.01
Dec-94	1.41	1.27	0.04	3.35	0.05	0.23	0.01
Jan-95	1.43	1.29	0.04	3.40	0.05	0.23	0.01
Feb-95	1.43	1.29	0.04	3.40	0.05	0.23	0.01
Mar-95	1.43	1.29	0.04	3.40	0.05	0.23	0.01
Apr-95	1.43	1.29	0.04	3.40	0.07	0.32	0.01
May-95	1.43	1.29	0.04	3.40	0.07	0.32	0.01
Jun-95	1.43	1.29	0.04	3.40	0.09	0.45	0.02
Jul-95	1.43	1.29	0.04	3.40	0.09	0.45	0.02
Aug-95	1.43	1.29	0.04	3.40	0.09	0.45	0.02
Sep-95	1.43	1.29	0.04	3.40	0.09	0.45	0.02

Low water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Oct-95	1.43	1.29	0.04	3.40	0.07	0.32	0.01
Nov-95	1.43	1.29	0.04	3.40	0.07	0.32	0.01
Dec-95	1.43	1.29	0.04	3.40	0.05	0.23	0.01
Jan-96	1.45	1.30	0.04	3.44	0.05	0.23	0.01
Feb-96	1.45	1.30	0.04	3.44	0.05	0.23	0.01
Mar-96	1.45	1.30	0.04	3.44	0.05	0.23	0.01
Apr-96	1.45	1.30	0.04	3.44	0.07	0.33	0.01
May-96	1.45	1.30	0.04	3.44	0.07	0.33	0.01
Jun-96	1.45	1.30	0.04	3.44	0.09	0.45	0.02
Jul-96	1.45	1.30	0.04	3.44	0.09	0.45	0.02
Aug-96	1.45	1.30	0.04	3.44	0.09	0.45	0.02
Sep-96	1.45	1.30	0.04	3.44	0.09	0.45	0.02
Oct-96	1.45	1.30	0.04	3.44	0.07	0.33	0.01
Nov-96	1.45	1.30	0.04	3.44	0.07	0.33	0.01
Dec-96	1.45	1.30	0.04	3.44	0.05	0.23	0.01
Jan-97	1.47	1.32	0.04	3.49	0.05	0.24	0.01
Feb-97	1.47	1.32	0.04	3.49	0.05	0.24	0.01
Mar-97	1.47	1.32	0.04	3.49	0.05	0.24	0.01
Apr-97	1.47	1.32	0.04	3.49	0.07	0.33	0.01
May-97	1.47	1.32	0.04	3.49	0.07	0.33	0.01
Jun-97	1.47	1.32	0.04	3.49	0.10	0.46	0.02
Jul-97	1.47	1.32	0.04	3.49	0.10	0.46	0.02
Aug-97	1.47	1.32	0.04	3.49	0.10	0.46	0.02
Sep-97	1.47	1.32	0.04	3.49	0.10	0.46	0.02
Oct-97	1.47	1.32	0.04	3.49	0.07	0.33	0.01
Nov-97	1.47	1.32	0.04	3.49	0.07	0.33	0.01
Dec-97	1.47	1.32	0.04	3.49	0.05	0.24	0.01
Jan-98	1.48	1.34	0.04	3.53	0.05	0.24	0.01
Feb-98	1.48	1.34	0.04	3.53	0.05	0.24	0.01
Mar-98	1.48	1.34	0.04	3.53	0.05	0.24	0.01
Apr-98	1.48	1.34	0.04	3.53	0.07	0.34	0.01
May-98	1.48	1.34	0.04	3.53	0.07	0.34	0.01
Jun-98	1.48	1.34	0.04	3.53	0.10	0.47	0.02
Jul-98	1.48	1.34	0.04	3.53	0.10	0.47	0.02
Aug-98	1.48	1.34	0.04	3.53	0.10	0.47	0.02
Sep-98	1.48	1.34	0.04	3.53	0.10	0.47	0.02
Oct-98	1.48	1.34	0.04	3.53	0.07	0.34	0.01
Nov-98	1.48	1.34	0.04	3.53	0.07	0.34	0.01
Dec-98	1.48	1.34	0.04	3.53	0.05	0.24	0.01

High water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jan-86	1.43	1.37	0.15	3.31	0.07	0.29	0.07
Feb-86	1.43	1.37	0.15	3.31	0.07	0.29	0.07
Mar-86	1.43	1.37	0.15	3.31	0.07	0.29	0.07
Apr-86	1.43	1.37	0.15	3.31	0.09	0.41	0.09
May-86	1.43	1.37	0.15	3.31	0.09	0.41	0.09
Jun-86	1.43	1.37	0.15	3.31	0.13	0.57	0.13
Jul-86	1.43	1.37	0.15	3.31	0.13	0.57	0.13
Aug-86	1.43	1.37	0.15	3.31	0.13	0.57	0.13
Sep-86	1.43	1.37	0.15	3.31	0.13	0.57	0.13

High water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Oct-86	1.43	1.37	0.15	3.31	0.09	0.41	0.09
Nov-86	1.43	1.37	0.15	3.31	0.09	0.41	0.09
Dec-86	1.43	1.37	0.15	3.31	0.07	0.29	0.07
Jan-87	1.52	1.45	0.16	3.51	0.07	0.31	0.07
Feb-87	1.52	1.45	0.16	3.51	0.07	0.31	0.07
Mar-87	1.52	1.45	0.16	3.51	0.07	0.31	0.07
Apr-87	1.52	1.45	0.16	3.51	0.10	0.43	0.10
May-87	1.52	1.45	0.16	3.51	0.10	0.43	0.10
Jun-87	1.52	1.45	0.16	3.51	0.14	0.60	0.14
Jul-87	1.52	1.45	0.16	3.51	0.14	0.60	0.14
Aug-87	1.52	1.45	0.16	3.51	0.14	0.60	0.14
Sep-87	1.52	1.45	0.16	3.51	0.14	0.60	0.14
Oct-87	1.52	1.45	0.16	3.51	0.10	0.43	0.10
Nov-87	1.52	1.45	0.16	3.51	0.10	0.43	0.10
Dec-87	1.52	1.45	0.16	3.51	0.07	0.31	0.07
Jan-88	1.61	1.54	0.17	3.72	0.08	0.33	0.08
Feb-88	1.61	1.54	0.17	3.72	0.08	0.33	0.08
Mar-88	1.61	1.54	0.17	3.72	0.08	0.33	0.08
Apr-88	1.61	1.54	0.17	3.72	0.11	0.46	0.11
May-88	1.61	1.54	0.17	3.72	0.11	0.46	0.11
Jun-88	1.61	1.54	0.17	3.72	0.15	0.64	0.15
Jul-88	1.61	1.54	0.17	3.72	0.15	0.64	0.15
Aug-88	1.61	1.54	0.17	3.72	0.15	0.64	0.15
Sep-88	1.61	1.54	0.17	3.72	0.15	0.64	0.15
Oct-88	1.61	1.54	0.17	3.72	0.11	0.46	0.11
Nov-88	1.61	1.54	0.17	3.72	0.11	0.46	0.11
Dec-88	1.61	1.54	0.17	3.72	0.08	0.33	0.08
Jan-89	1.70	1.63	0.18	3.94	0.08	0.35	0.08
Feb-89	1.70	1.63	0.18	3.94	0.08	0.35	0.08
Mar-89	1.70	1.63	0.18	3.94	0.08	0.35	0.08
Apr-89	1.70	1.63	0.18	3.94	0.11	0.49	0.11
May-89	1.70	1.63	0.18	3.94	0.11	0.49	0.11
Jun-89	1.70	1.63	0.18	3.94	0.16	0.67	0.16
Jul-89	1.70	1.63	0.18	3.94	0.16	0.67	0.16
Aug-89	1.70	1.63	0.18	3.94	0.16	0.67	0.16
Sep-89	1.70	1.63	0.18	3.94	0.16	0.67	0.16
Oct-89	1.70	1.63	0.18	3.94	0.11	0.49	0.11
Nov-89	1.70	1.63	0.18	3.94	0.11	0.49	0.11
Dec-89	1.70	1.63	0.18	3.94	0.08	0.35	0.08
Jan-90	1.73	1.65	0.18	3.99	0.08	0.35	0.08
Feb-90	1.73	1.65	0.18	3.99	0.08	0.35	0.08
Mar-90	1.73	1.65	0.18	3.99	0.08	0.35	0.08
Apr-90	1.73	1.65	0.18	3.99	0.11	0.49	0.11
May-90	1.73	1.65	0.18	3.99	0.11	0.49	0.11
Jun-90	1.73	1.65	0.18	3.99	0.16	0.68	0.16
Jul-90	1.73	1.65	0.18	3.99	0.16	0.68	0.16
Aug-90	1.73	1.65	0.18	3.99	0.16	0.68	0.16
Sep-90	1.73	1.65	0.18	3.99	0.16	0.68	0.16
Oct-90	1.73	1.65	0.18	3.99	0.11	0.49	0.11
Nov-90	1.73	1.65	0.18	3.99	0.11	0.49	0.11
Dec-90	1.73	1.65	0.18	3.99	0.08	0.35	0.08
Jan-91	1.75	1.67	0.18	4.05	0.08	0.36	0.08

High water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Feb-91	1.75	1.67	0.18	4.05	0.08	0.36	0.08
Mar-91	1.75	1.67	0.18	4.05	0.08	0.36	0.08
Apr-91	1.75	1.67	0.18	4.05	0.12	0.50	0.12
May-91	1.75	1.67	0.18	4.05	0.12	0.50	0.12
Jun-91	1.75	1.67	0.18	4.05	0.16	0.69	0.16
Jul-91	1.75	1.67	0.18	4.05	0.16	0.69	0.16
Aug-91	1.75	1.67	0.18	4.05	0.16	0.69	0.16
Sep-91	1.75	1.67	0.18	4.05	0.16	0.69	0.16
Oct-91	1.75	1.67	0.18	4.05	0.12	0.50	0.12
Nov-91	1.75	1.67	0.18	4.05	0.12	0.50	0.12
Dec-91	1.75	1.67	0.18	4.05	0.08	0.36	0.08
Jan-92	1.77	1.70	0.19	4.10	0.08	0.36	0.08
Feb-92	1.77	1.70	0.19	4.10	0.08	0.36	0.08
Mar-92	1.77	1.70	0.19	4.10	0.08	0.36	0.08
Apr-92	1.77	1.70	0.19	4.10	0.12	0.51	0.12
May-92	1.77	1.70	0.19	4.10	0.12	0.51	0.12
Jun-92	1.77	1.70	0.19	4.10	0.16	0.70	0.16
Jul-92	1.77	1.70	0.19	4.10	0.16	0.70	0.16
Aug-92	1.77	1.70	0.19	4.10	0.16	0.70	0.16
Sep-92	1.77	1.70	0.19	4.10	0.16	0.70	0.16
Oct-92	1.77	1.70	0.19	4.10	0.12	0.51	0.12
Nov-92	1.77	1.70	0.19	4.10	0.12	0.51	0.12
Dec-92	1.77	1.70	0.19	4.10	0.08	0.36	0.08
Jan-93	1.79	1.72	0.19	4.15	0.08	0.37	0.08
Feb-93	1.79	1.72	0.19	4.15	0.08	0.37	0.08
Mar-93	1.79	1.72	0.19	4.15	0.08	0.37	0.08
Apr-93	1.79	1.72	0.19	4.15	0.12	0.51	0.12
May-93	1.79	1.72	0.19	4.15	0.12	0.51	0.12
Jun-93	1.79	1.72	0.19	4.15	0.16	0.71	0.16
Jul-93	1.79	1.72	0.19	4.15	0.16	0.71	0.16
Aug-93	1.79	1.72	0.19	4.15	0.16	0.71	0.16
Sep-93	1.79	1.72	0.19	4.15	0.16	0.71	0.16
Oct-93	1.79	1.72	0.19	4.15	0.12	0.51	0.12
Nov-93	1.79	1.72	0.19	4.15	0.12	0.51	0.12
Dec-93	1.79	1.72	0.19	4.15	0.08	0.37	0.08
Jan-94	1.82	1.74	0.19	4.21	0.09	0.37	0.09
Feb-94	1.82	1.74	0.19	4.21	0.09	0.37	0.09
Mar-94	1.82	1.74	0.19	4.21	0.09	0.37	0.09
Apr-94	1.82	1.74	0.19	4.21	0.12	0.52	0.12
May-94	1.82	1.74	0.19	4.21	0.12	0.52	0.12
Jun-94	1.82	1.74	0.19	4.21	0.17	0.72	0.17
Jul-94	1.82	1.74	0.19	4.21	0.17	0.72	0.17
Aug-94	1.82	1.74	0.19	4.21	0.17	0.72	0.17
Sep-94	1.82	1.74	0.19	4.21	0.17	0.72	0.17
Oct-94	1.82	1.74	0.19	4.21	0.12	0.52	0.12
Nov-94	1.82	1.74	0.19	4.21	0.12	0.52	0.12
Dec-94	1.82	1.74	0.19	4.21	0.09	0.37	0.09
Jan-95	1.84	1.76	0.19	4.26	0.09	0.38	0.09
Feb-95	1.84	1.76	0.19	4.26	0.09	0.38	0.09
Mar-95	1.84	1.76	0.19	4.26	0.09	0.38	0.09
Apr-95	1.84	1.76	0.19	4.26	0.12	0.53	0.12
May-95	1.84	1.76	0.19	4.26	0.12	0.53	0.12

High water user – High water conservation							
	Kitchen sink	Hand basin	Dish washer	Toilet	Washing machine	Shower	Outdoor uses
Jun-95	1.84	1.76	0.19	4.26	0.17	0.73	0.17
Jul-95	1.84	1.76	0.19	4.26	0.17	0.73	0.17
Aug-95	1.84	1.76	0.19	4.26	0.17	0.73	0.17
Sep-95	1.84	1.76	0.19	4.26	0.17	0.73	0.17
Oct-95	1.84	1.76	0.19	4.26	0.12	0.53	0.12
Nov-95	1.84	1.76	0.19	4.26	0.12	0.53	0.12
Dec-95	1.84	1.76	0.19	4.26	0.09	0.38	0.09
Jan-96	1.86	1.79	0.20	4.32	0.09	0.38	0.09
Feb-96	1.86	1.79	0.20	4.32	0.09	0.38	0.09
Mar-96	1.86	1.79	0.20	4.32	0.09	0.38	0.09
Apr-96	1.86	1.79	0.20	4.32	0.12	0.53	0.12
May-96	1.86	1.79	0.20	4.32	0.12	0.53	0.12
Jun-96	1.86	1.79	0.20	4.32	0.17	0.74	0.17
Jul-96	1.86	1.79	0.20	4.32	0.17	0.74	0.17
Aug-96	1.86	1.79	0.20	4.32	0.17	0.74	0.17
Sep-96	1.86	1.79	0.20	4.32	0.17	0.74	0.17
Oct-96	1.86	1.79	0.20	4.32	0.12	0.53	0.12
Nov-96	1.86	1.79	0.20	4.32	0.12	0.53	0.12
Dec-96	1.86	1.79	0.20	4.32	0.09	0.38	0.09
Jan-97	1.89	1.81	0.20	4.37	0.09	0.39	0.09
Feb-97	1.89	1.81	0.20	4.37	0.09	0.39	0.09
Mar-97	1.89	1.81	0.20	4.37	0.09	0.39	0.09
Apr-97	1.89	1.81	0.20	4.37	0.12	0.54	0.12
May-97	1.89	1.81	0.20	4.37	0.12	0.54	0.12
Jun-97	1.89	1.81	0.20	4.37	0.17	0.75	0.17
Jul-97	1.89	1.81	0.20	4.37	0.17	0.75	0.17
Aug-97	1.89	1.81	0.20	4.37	0.17	0.75	0.17
Sep-97	1.89	1.81	0.20	4.37	0.17	0.75	0.17
Oct-97	1.89	1.81	0.20	4.37	0.12	0.54	0.12
Nov-97	1.89	1.81	0.20	4.37	0.12	0.54	0.12
Dec-97	1.89	1.81	0.20	4.37	0.09	0.39	0.09
Jan-98	1.91	1.83	0.20	4.43	0.09	0.39	0.09
Feb-98	1.91	1.83	0.20	4.43	0.09	0.39	0.09
Mar-98	1.91	1.83	0.20	4.43	0.09	0.39	0.09
Apr-98	1.91	1.83	0.20	4.43	0.13	0.55	0.13
May-98	1.91	1.83	0.20	4.43	0.13	0.55	0.13
Jun-98	1.91	1.83	0.20	4.43	0.17	0.76	0.17
Jul-98	1.91	1.83	0.20	4.43	0.17	0.76	0.17
Aug-98	1.91	1.83	0.20	4.43	0.17	0.76	0.17
Sep-98	1.91	1.83	0.20	4.43	0.17	0.76	0.17
Oct-98	1.91	1.83	0.20	4.43	0.13	0.55	0.13
Nov-98	1.91	1.83	0.20	4.43	0.13	0.55	0.13
Dec-98	1.91	1.83	0.20	4.43	0.09	0.39	0.09

Annex V – Scientific publications produced

a. Παρουσίαση της δομής και των βασικών στόχων της διδακτορικής έρευνας στη 3η Συνάντηση Υποψηφίων Διδακτόρων που διοργανώθηκε από το δίκτυο Υδρομέδων, 12 Ιουλίου 2011, Αθήνα

b. Koutiva I. and Makropoulos C. (2011), "Towards adaptive water resources management: Simulating the complete socio-technical system through computational intelligence", 12th International Conference on Environmental Science and Technology (CEST 2011)

c. Koutiva I. and Makropoulos C. (2012), "Linking social simulation and urban water modelling tools to support adaptive urban water management", R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) (2012): International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software. Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Sixth Biennial Meeting, Leipzig, Germany.

d. Baki S., Koutiva I. and Makropoulos C. (2012), "A hybrid artificial intelligence modeling framework for the simulation of the complete, socio-technical, urban water system", R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) (2012): International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software. Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Sixth Biennial Meeting, Leipzig, Germany.»

e. Koutiva I., Makropoulos C. and Voulvoulis N. (2012), "Modelling the combined socio-technical system to support an adaptive approach for Integrated Water Resources Management", proceedings of the 10th International Conference on Hydroinformatics, HIC 2012, Hamburg, Germany

f. Koutiva I., Gerakopoulou, P., Makropoulos C. and Vernardakis, C. (2015), "Exploration of domestic water demand attitudes using qualitative and quantitative social research methods", Accepted for publication, Urban Water Journal, Taylor and Francis

g. Koutiva I. and Makropoulos C. (2015), “Modelling domestic water demand: an agent based approach”, Under Review, Environmental Software and Modelling, Elsevier

h. Koutiva I. and Makropoulos C. (2015), “Simulating the domestic water demand behaviour using agent based modelling”, presented in poster session in 14th International, Conference on Environmental Science and Technology, CEST2015, 3-5 September 2015, Rhodes, Greece

i. Koutiva I. and Makropoulos C. (2015), “Exploration of domestic water demand attitudes and behaviours using an online survey in Athens, Greece”, Koutiva I. and Makropoulos C., presented in 14th International Conference on Environmental Science and Technology, CEST2015, 3-5 September 2015, Rhodes, Greece

j. Koutiva I. and Makropoulos C. (2015), “Exploring the effects of domestic water management measures to water conservation attitudes using Agent Based Modelling”, Under Review, Water Science and Technology, IWA Publishing