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An integrated System Dynamic – Cellular Automata model for distributed water-infrastructure planning

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Modern distributed water-aware technologies (including, for example, grey water recycling and rainwater harvesting) enable water reuse at the scale of household or neighbourhood. Nevertheless, even though these technologies are in some cases economically advantageous, they have a significant handicap compared to the centralized urban water management options: it is not easy to estimate a priori the extent and the rate of the technology spread. This disadvantage is amplified in case of additional uncertainty due to expansion of an urban area. This overall incertitude is one of the basic reasons the stakeholders involved in urban water are sceptical about the distributed technologies, even in the cases these appear to have lower cost. In this study, we suggest a methodology that attempts to cope with this uncertainty by coupling a Cellular Automata and a System Dynamics model. The Cellular Automata model is used to create scenarios of urban expansion including the suitability of installing water-aware technologies for each new urban area. Then, the System Dynamics model is used to estimate the adoption rate of the technologies. Various scenarios based on different economic conditions and water prices are assessed. The suggested methodology is applied to an urban area in Attica, Greece.

Keywords: cellular automata; distributed water-saving technologies; system dynamics; urban water cycle

INTRODUCTION

Water scarcity is one of the most serious modern-day problems with a continuously growing list of affected regions. Both international organizations and local governments have officially acknowledged this problem (Vorosmarty et al., 2000; Rosegrant et al., 2002) and have acted accordingly either by funding related research programs (the scientific community has been studying water scarcity for the last few decades) or by directly taking water demand management measures or by appropriate subsidies. As a result, there are nowadays examples of good practices/techniques that achieve considerable reduction of water demand. At the household level, these include rainwater harvesting, greywater recycling and low consumption water appliances.

Despite the existence of a considerable number of success stories (Styles and Keating, 2000; Nolde, 2007; Davis and Farrely, 2009; Paris and Schlapp, 2010; Lee et al., 2011) stakeholders are still very sceptical about distributed options and prefer the standard approach: increase the capacity of mains when the demand comes to a critical point. Taking into account that even with the economies of scale, such centralized interventions tend to be very expensive (the overall cost including, for example, disruptions of activities, knock-on effects on the rest part of the network that can result in needs for a greater extent of renovations or replacements, environmental costs because of additional pressure on water resources, etc.), it seems like an obsession of stakeholders to insist on the standard approach.

However, stakeholders have a good reason to be sceptical about distributed options. The installation of distributed options depends on whether each individual household owner can afford to undertake the required expenses. For this reason, the installation cannot be mandated, but only motivated. As a result, the distributed options introduce an additional uncertainty in the urban water management decisions: to what extent and how fast water-aware technologies will be adopted.

To address this issue, Bouziotas et al. (2015) attempted to simulate the aspects of the interplay between the dynamics of urban growth and the urban water cycle. Specifically, a Cellular Automata (CA) urban growth model provided the growth patterns at the level of detail needed by the urban water cycle model UWOT (Makropoulos et al., 2008). The resulting toolkit simulated the spatial changes in urban areas while simultaneously estimated their water demand impact under different water demand management scenarios, with an emphasis on distributed technologies whose applicability depends on urban form.

Though Bouziotas et al. (2015) used a sophisticated method to estimate the evolution of demand due to the expansion of an urban area, they employed a rather oversimplified approach to estimate the installation of distributed water-aware technologies: they assumed a constant (unjustified) adoption rate.

In this study we try to remedy this weak point by linking the urban water cycle and CA model used by Bouziotas et al. (2015) with a custom-built SD model. SD models have been recently used successfully to study urban water supply security (Chang et al., 2015). On the other hand, CA alone or combined with SD models have been successfully applied for studying exclusively land-use scenario dynamics (Chunyang et al., 2005; Haase and Schwarz, 2009; Han et al., 2009). However, the coupling of CA and SD models has not been applied so far to study thoroughly the urban water demand taking into account both the land-use and the socio-economic dynamics.

METHODS

CA model

The CA model used in this study is described in the publication of Bouziotas et al. (2015). This model supports arbitrary number of cell states. Each state can be associated with different urban properties. This multi-state approach allows for a more detailed spatial (raster) representation of the urbanization process. The state of each cell of the raster representation can change (following predefined rules) either because of urban expansion or because of urban intensification. Another novelty of this model is that it employs two parameters to estimate the probability of a CA cell to change from one state to another. These two parameters are the suitability factor, which is related to the desirability for urbanisation, and the velocity factor, which denotes the intensity with which the rules are applied.

UWOT – the urban water cycle model

UWOT is an urban water cycle model that acknowledges every urban water flow as result of a demand. For this reason, it simulates demand signals instead of flows (i.e. the cause instead of the effect). This approach has the advantage of directly representing the principal purpose of infrastructure, which is to serve the need for water supply and wastewater disposal.

UWOT (Rozos et al., 2013; Rozos and Makropoulos, 2013, 2012) distinguishes between two signal types, the push and pull signals. The push signals express a need to dispose a specific volume of water (e.g. the output of a washing machine). The pull signals express a demand for a specific volume of water (e.g. the water required for the operation of a washing machine). The water flows on the same direction with push signals whereas flows on the opposite direction of pull signals. Another difference between push and pull signals is that pull signals do not bear a qualitative characterization because the water that covers a demand is assumed to meet the quality standards imposed by regulations. On the other hand, push signals are characterized by a qualitative value that can express any preselected water quality parameter (a single preselected parameter for each UWOT project).

The specifications of the water appliances are stored in a database called “Technology Library”. Based on these specifications, UWOT estimates the demand signals emitted from the household appliances. These signals are aggregated at household level or at a higher level if necessary. The high level demand signals can be routed to different water resources according to the qualitative and quantitative conditions of each resource.

UWOT was used to simulate two representative household configurations. The first one is the business as usual (BAU) configuration that includes conventional household appliances and no water saving/recycling scheme. The other configuration includes a water-saving scheme (WSS) in which the bath/kitchen faucets and the toilet are replaced with low-consumption ones, and a rainwater harvesting scheme is installed. The household occupancy is 3 persons in both configurations.

SD model

An SD model was developed to simulate the adoption of the WSS. It is assumed that each year some owners of the conventional households examine the installation of the scheme and decide to either install or reject it. The rate of the installation of the scheme is affected by the price of water and the economic conditions. The higher the water price, the higher the rate of installation and the lower the rejection rate, and vice versa. On the other hand, an improvement of the economic conditions, expressed here in terms of the index of consumer sentiment (CONSSENT), is expected to encourage installation. The causal-loop diagram of the SD model is shown in the following figure.

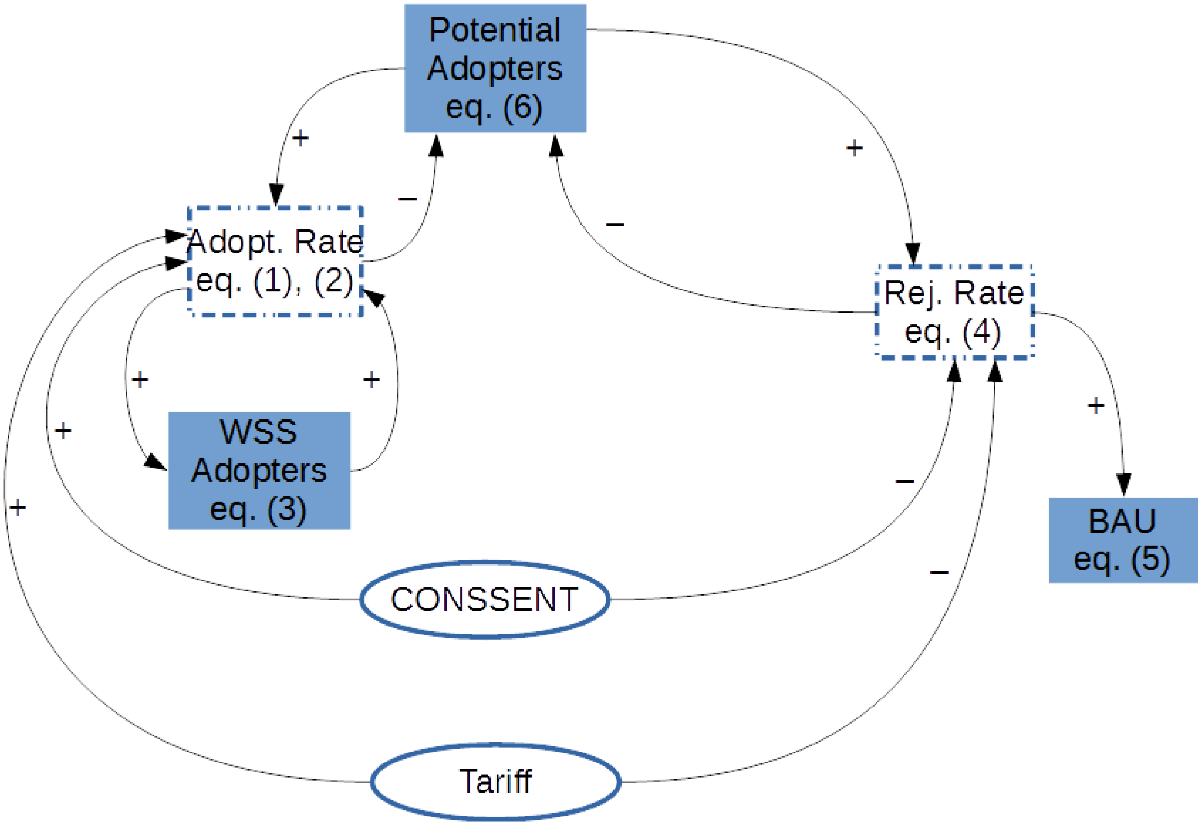

Figure 1. Causal-loop diagram of the SD model. With blue shaded frames the stocks, with dotted-dashed frames the flows (the corresponding governing equations are indicated inside the frames) and with ellipses the exogenous variables.

Figure 1, among other relationships, exhibits the typical pair of loops of a technology penetration (Sterman, 2000). This pair includes the market saturation and the word-of-mouth loops. The first is a balanced loop, i.e. there is a negative feedback relationship that controls the evolution of the process. This is displayed in Figure 1 with the loop between the stock “Potential Adopters” and the flow “Adoption Rate” of which loop the two branches are marked with “+” and “–” respectively. The second loop (fashion) is a self-reinforcing loop, in which both relationships act on the same direction resulting in a slow start with gradual acceleration. This is displayed in Figure 1 with the loop between the flow “Adoption Rate” and the stock “WSS Adopters” of which loop both branches are marked with “+”.

Regarding the saturation of the market, the first relationship of this loop corresponds to the positive link between the “Potential Adopters” and “Adoption Rate”, i.e. the more the available households to consider the installation of a scheme, the greater the maximum possible installation rate (inversely, if no household remains to consider the installation, then the installation rate will be zero). The second relationship represents the reduction of the available households for installation as more and more conventional households turn into WSS.

Regarding the word-of-mouth loop, the first relationship of this loop corresponds to the positive link between the adoption rate of WSS and the number of WSS adopters, i.e. the installation of WSS technologies increases the number of the households with WSS (logical). The second relationship corresponds to the positive link between the number of households that have installed WSS and the rate of the installation (the more the people that have installed it, the more the people that will imitate). In this study, we assumed that the word-of-mouth does not apply to the rejection of technology installation because rejection is essentially no different from the status quo and hence it has nothing to do with imitating a new practice. However, it should be noted that other studies assume that the non-innovators are more likely to copy rejection (Mooy, 2004).

The simulation time step is one year. The mathematical formulas of the loops described previously are given below.

The flow “Adoption Rate” (both because of innovation and imitation) is calculated by the following equations:

$$\mathrm{im}_i = \mathrm{dt}\, q\, \mathrm{ad}_{i\text{-}1}\, P_{i\text{-}1} \qquad (1)$$

$$\mathrm{iv}_i = \mathrm{dt}\, p\, \mathrm{pot}_{i\text{-}1} \qquad (2)$$

The stock “WSS Adopters” is calculated by the following equation:

$$\mathrm{ad}_i = \sum(\mathrm{iv}_j + \mathrm{im}_j)\ \mathrm{Mad},\ \text{where } j=0,\ldots,i \qquad (3)$$

The flow “Rejection Rate” is calculated by the following equation:

$$\mathrm{iv0}_i = \mathrm{dt}\,\rho\,\mathrm{pot}_{i\text{-}1} \tag{4}$$

The stock “BAU” is calculated by the following equation:

$$\mathrm{rej}_i = \sum \mathrm{iv0}_j \,/\, \mathrm{Mad}, \text{ where } j=0,\ldots,i \tag{5}$$

The stock “Potential Adopters” is calculated by the following equation:

$$\mathrm{pot}_i = \mathrm{pot}_0 - (\mathrm{ad}_i + \mathrm{rej}_i) \tag{6}$$

At the end of each iteration, the probability a household has not considered technology installation (required in equation (1)) is calculated by the equation:

$$P_i = \mathrm{pot}_i \,/\, \mathrm{pot}_0 \tag{7}$$

where:

i	the simulation step
im_i	the number of WSSs installed at i because of imitation
q	the rate of adoption imitation (year^{-1})
iv_i	the number of WSSs installed at i because of innovation
p	the rate of adoption innovation (year^{-1})
ad_i	the number of households that have adopted WSS up to time step i
dt	the time step (year)
Mad	see equation (12)
$\mathrm{iv0}_i$	the number of households rejected to install WSS at time step i
ρ	the rate of rejection innovation (year^{-1})
rej_i	the number of households that have rejected WSS up to time step i
P_i	the probability a household has not considered WSS installation at i
pot_0	initial population of conventional households
pot_i	the number of households that up to i have not considered WSS installation

The two innovation parameters (p and ρ) reflect the attitude of a specific society under specific socio-economic conditions towards a specific technology. Consequently, a survey is required to estimate them (calibration may be required to reproduce the survey findings, e.g. the willingness to install a technology).

On the other hand, the imitation coefficient (q) stems from a basic characteristic of the social nature of human beings. Therefore, it is assumed that this coefficient will not depend on socio-economic conditions and for this reason can be obtained from literature.

The price of water ("Tariff" in Figure 1) is an exogenous variable that represents the single most effective policy used to control the water demand. The influence of this policy is estimated with the following formula:

$$\mathrm{Fng} = 1 + \alpha\, \mathrm{Mtr} \qquad (8)$$

where Fng is the relative change of a scheme's adoption rate caused by a tariff change, Mtr is the relative change of water-price, and α is a parameter.

As far as concerns the economic conditions, a simplified version of the formula suggested by Carroll et al. (1994) that links the consumer price index with the consumption is used. Here it is assumed that the change of consumption this formula forecasts can be applied directly to the increase of water-saving technologies installation rate. According to Carroll et al.:

$$\Delta \log(C_t) = a_0 + \sum b_i\, S_{t-i} + \varepsilon_t,\ \ i = 1,\dots 4 \qquad (9)$$

where C_t is the consumption at the time step t and S_{t-i} is the Consumer Sentiment Index (CONSSENT) at the time step $t–i$. For simplification, it is assumed that $a_0=b_3=b_4=\varepsilon_t= 0$, $b_1=\beta$, and $b_2= -\beta$. Furthermore, it is assumed that there is a representative CONSSENT value S for the whole time period simulated by the SD model and a corresponding value of consumption C. These values are compared against reference values S_0 and C_0. If Cng is the ratio of the consumption change for CONSSENT changing from S_0 to S then equation (9) becomes:

$$\log(\mathrm{Cng}) = \beta\,(S - S_0) \qquad (10)$$

or

$$\mathrm{Cng} = \exp(\beta\,(S - S_0)) \qquad (11)$$

Combining equation (8) and (11) the total influence of the two exogenous variables on the dynamics of the system is derived:

$$\mathrm{Mad} = \mathrm{Fng}\ \mathrm{Cng} \qquad (12)$$

It should be noted that the previous equations are for simulating the adoption of only one water-saving option. If more water-saving options are to be studied, then the corresponding imitation and innovation equations should be added and equation (3) should be modified accordingly.

CASE STUDY

The studied area was the Artemis district of Attica prefecture, Greece. This area was selected because both the existing and the forecasted, according to the CA model, new households (mostly single-family buildings with large garden) are suitable for the kind of water saving technology examined by the SD model. The CA model of Bouziotas et al. (2015) for this area forecasts an increase from 528 households in 2010 to 634 households in 2020. Therefore, if no intervention, the water demand is expected to increase by 20.1%.

To mitigate this increase, a campaign to persuade people to install the WSS is examined. The UWOT simulations Bouziotas et al. (2015) made indicated that the demand of the BAU is 182 litres per capita per day whereas the demand of the WSS (taking into account climatic conditions of Artemis) drops to 79 litres per capita per day. A recent survey (Vernardakis, 2013) found that at least 15.4% of the household owners are not rejecting a priori the installation of a rainwater harvesting scheme. It is assumed that the campaign will persuade this 15.4%.

Model parameters

The parameter p was set equal to the median of the values reported in Table 1 of the Bass' (1969) study whereas ρ was calibrated to have SD model reproduce the 15.4% adoption ratio (it takes 10 years for the 15.4% to be reached and after that, adoption rates are almost zero).

As mentioned earlier, the parameter q (the rate of adoption imitation) is derived as the average of the q values appearing in Table 1 of the Bass' (1969).

The parameter α of equation (8) was calibrated to reproduce the 41% decrease of the Athens water demand during the 1990-1992 period, when the water price increased by 280% (Xenos et al., 2002). This implies the presupposition that the reduction of the water demand is expected to be achieved exclusively because of the introduction of water saving technologies.

The parameter β is estimated using the following technique. The derivative of equation (11) is $\beta \exp(\beta (S - S_0))$. Since Cng, and consequently $\exp(\beta (S - S_0))$, is expected to be close to 1 (the change of consumption ranges from -10 to 10% according to Figure 1 of Carroll et al. (1994), which means Cng is expected to range between 0.9 and 1.1) it can be derived that:

$$\mathrm{d\,Cng} / \mathrm{d}\,S \approx \beta \qquad (13)$$

The previous equation suggests that β can be estimated from the average derivative of Cng with respect to S. Annual percent change of personal consumption was plotted against consumer sentiment (both taken from of Figure 1 of Carroll et al. publication). The linear trend-line that fits best to these points had a slope equal to 0.00103. The parameters used in the SD model and their values can be seen in Table 1 (see “Nominal value” column).

Stakeholder decisions

A typical decision-making methodology is the one known with the acronym GOFER (Mann, 1989) derived from the initials of the followed steps: Goals, Options, Facts, Effects and Review. The Goal here is the smooth water supply. The Fact is that in this case study the capacity of the water supply system is (hypothetically) 5% larger than the 2010 water demand; therefore, without any intervention the urban expansion will drive the water supply system over its capacity in 3 years (starting from 2010). Two intervention Options are examined. The first option is the water-saving campaign. If the campaign alone is not sufficient, the second option includes an additional tariff policy that will satisfy the constraints with the minimal water-price increase.

The impacts of the campaign (i.e. the Effects) and the tariff policy are examined for three alternative economic scenarios: i) CONSSENT remains constant to the 2010 value (according to tradingeconomics.com is –47 for Greece) , ii) CONSSENT increases to the historically high value (–5, happened in 1988) and iii) CONSSENT decreases to the historically low (–83, happened in 2012). For all cases the reference CONSSENT value S_0 used in equation (11) is the one recorded in the year 2010.

RESULTS AND DISCUSSION

The evolution of the water demand of the Artemis district for the period between 2010 and 2020 taking into account the urban expansion, as it is forecasted by the CA model, and for the adoption rate of the WSS that the SD model estimated for various socio-economic scenarios, is shown in Figure 2.

According to this figure, with no intervention, there is a linear water demand increase that follows the urban expansion resulting in 20.1% more water required at the end of the studied period (capacity constraint is surpassed in the 3rd year of the simulation). If a water saving campaign is applied, and with constant CONSSENT and tariff, the water demand at the end of simulation drops from 20.1% to 10.4%. With CONSSENT ranging from the historically low to the historically high, the demand increase ranges from 9.2 to 11.2%. Consequently, the campaign alone, even with favourable economic conditions, does not suffice to keep water demand increase below the upper limit of 5%.

The next intervention to be examined is the water price (along with the campaign). From Figure 2 it is inferred that, if the water price doubles (instantaneously at the beginning of the examined period), the water demand is expected, despite the urban expansion, to decrease by 13.4% (11.3 to 15.9% for CONSSENT ranging from historically low to historically high).

Regarding the cost analysis of the WSS, according to a recent study (Kaparos, 2014) the cost of installing a rainwater harvesting scheme is 1409 Euros and the operational cost is 65 Euros per year (DMTP, 2011). The cost of installing low consumption appliances is 269 Euros. Therefore, the acquisition cost (supply and installation labour) of the WSS is 1678 Euros. When it comes to investments, the payback period is an important index. In the studied area, during the period the acceptability survey was carried out (July 2013), the water policy in effect was to employ a block tariff. The water price of the first two blocks (including wastewater charges) was 0.75 Euros/m^3 (up to 5 m^3 per month) and 1.28 Euros/m^3 (up to 20 m^3 per month). Assuming household occupancy is

3, the annual net profit (after deducting operational costs) is 47.78 Euros and the payback period, assuming a constant interest rate equal to 2%, is 60 years (this explains the very low adoption, close to 15% according to the SD simulations). If the water price of both blocks doubles, the annual net profit becomes 160.56 Euros and the payback period drops to 12 years. Consequently, there is a strong motivation to install the WSS, which the SD simulations captured by estimating that 52% of the population would adopt the water saving scheme.

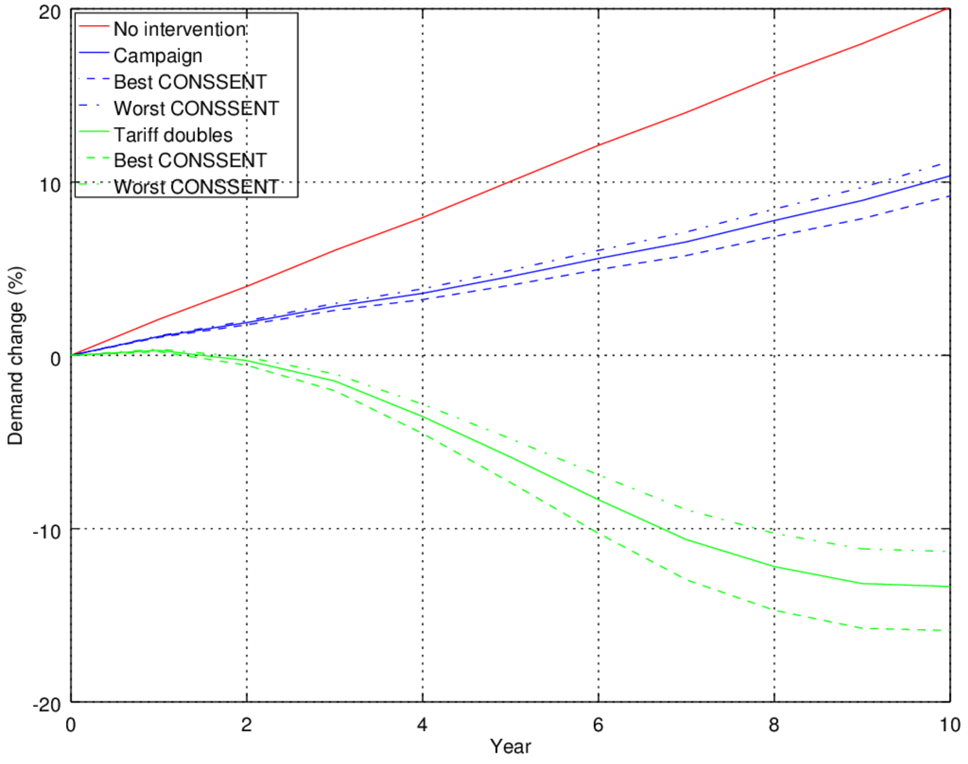

Figure 2. Evolution of demand of studied urban area for various CONSSENT values and the three intervention policies: no intervention, campaign, and campaign plus doubling the water price.

The demand reduction that water price doubling would bring is more than the required. Therefore, maybe there is room for a less drastic price increase (provided reliable estimations of the SD parameter values, see sensitivity analysis). To identify this optimal water price value, Figure 3 was prepared. This figure displays the estimated water demand increase of Artemis at the end of the simulation period for various values of water-price increase and for various CONSSENT values.

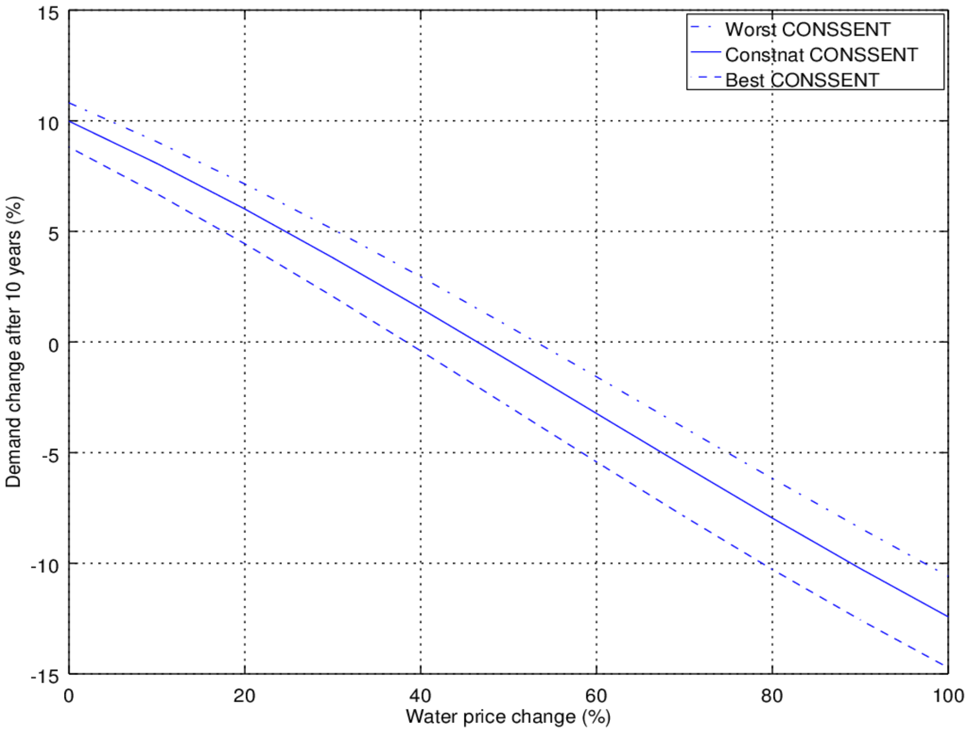

Figure 3. Demand change of studied urban area at the end of simulation for various water prices and CONSSENT values.

According to Figure 3, a water price increase of 32% along with the water-saving campaign will be all required to deter the water demand from exceeding the capacity of the water supply system even in case of unfavourable economic conditions.

This water price policy takes into account the uncertainty of the economic conditions, but not the uncertainty concerning the estimated values of the model parameters. For this reason, a sensitivity analysis was performed. Since all model equations are linear (except equation (11), which nevertheless has almost linear behaviour according to (13)) a local one-at-a-time sensitivity analysis was performed (Saltelli and Annoni, 2010). The results of this analysis (concerning the estimated water demand change after 10 years) for the previously suggested 32% water price increase and unfavourable economic conditions (CONSSENT = –83) are displayed in Table 1.

Table 1. SD model parameters' sensitivity analysis expressed as percentage change of demand for 1% increase of the parameter nominal value.

Parameter	**Nominal value**	**Change (%)**	**Adverse value**
p	0.0172	–2.23	-
ρ	0.167	2.68	-
q	0.3	–1.91	0.24
α	0.008	–1.40	0.002
β	0.00103	0.26	-

Table 1 displays the percentage change of final water demand for 1% increase of each one of the model parameters (separately). According to this table, the model results are not very sensitive to parameter β. Model is quite sensitive to p and ρ. However, the values of these parameters can be considered reliable since they were derived after calibration to reproduce survey findings. Parameters q and α need further examination. For this reason, the required water price increase to keep the demand increase below the 5% threshold was estimated again, this time for the adverse values of q and α displayed in Table 1.

For parameter q, the adverse value was assumed to be the one corresponding to the 20th percentile of the values reported in Table 1 of Bass' study (1969). Assuming unfavourable economic conditions (CONSSENT = –83) this new q value resulted in a required water price increase by 42% instead of 32%.

For parameter α, the adverse value was estimated (with recalibration, see section Model Parameters) from the most elastic response of Athens water demand for price increase given by Xenos et al. (2002). Assuming unfavourable economic conditions (CONSSENT = –83) this new α value resulted in a required water price increase by 128% instead of only 32%.

Consequently, an increase of water price by 128% along with the water saving campaign is a quite safe choice to ensure smooth operation of the water supply system for the next 10 years.

CONCLUSIONS

The principal objective of this study was to suggest a methodology that could help render distributed water-aware technologies a more trusted choice when a decision is about to be made regarding a foreseen capacity exceedance of the water supply system. Specifically, it is suggested at the first stage to use a CA model to produce scenarios of urban expansion. Subsequently, these scenarios should be fed into a System Dynamics model to study the adoption rate of the water-aware technologies. To take into account the influence of the macro-economic conditions, the SD model developed in this study uses as exogenous variable the consumer sentiment index. In case the SD model indicates that the normal adoption rate will not be sufficient to deter capacity exceedance, a water price policy can be examined by the SD model (tariff is another exogenous variable). The SD model is capable of preparing a chart of water price vs. forecasted demand from which the stakeholder could identify the minimum water price increase that would guarantee the adoption of the water-saving technologies from adequate number of households to ensure no capacity exceedance.

The SD model offers also the option to perform a sensitivity analysis. This analysis along with the perceived reliability of the data used in each specific case study can indicate the most critical parameters of which the values deserve a closer look. Then, alternative simulations can be performed with adverse values for these parameters to obtain a conservative water price policy that could minimize the risk of exceeding the water supply system capacity.

The methodology of this study is generic and could be applied to arbitrary locations provided a proper calibration of the SD model parameters. The required data includes surveys regarding the public attitude towards water-aware technologies plus water consumption vs. water price records.

Finally, it should be noted that the methodology described here did not take into account restrictions stemming from socio-economic factors. For example, the water price in Athens, Greece, between 1990 and 1992 almost tripled without any serious protests, probably because of the very low water price compared to the average income (as well as the sense of risk resulting from the then imminent drought (Koutiva and Makropoulos, 2016)). In fact, even after the price increased, there were instances where even low-class household owners (eyewitness memory) kept using water to wash their balconies, despite both constant awareness raising campaigns and new higher prices (possibly due to deeply engrained cultural norms, Koutiva et al., 2016). On the other hand there exist cases where water price increase led to civil unrest due to affordability challenges faced by the poorest parts of society (e.g. Maldonado, Uruguay). As such, it is suggested that additional considerations and factors should be taken into account as constraints in real world applications of the model, to ensure that simulated water price increases do not endanger the affordability of water services, especially for the poorest part of society.

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REFERENCES

Bass F.M. 1969 A New Product Growth Model for Consumer Durables. Management Science 15(5), 215–227.

Bouziotas D., Rozos E. and Makropoulos C. 2015 Water and the city: exploring links between urban growth and water demand management, Journal of Hydroinformatics, 17.2, 176-192.

Carroll C.D., Fuhrer J.C. and Wilcox D.W. 1994 Does consumer sentiment forecasting household spending? If so, why?. American Economic Review 84 (5), 1397–1408.

Chang Y., Liu H., Bao A., Chen X. and Wang L. 2015 Evaluation of urban water resource security under urban expansion using a system dynamics model, Water Science & Technology: Water Supply, 15 (6), 1259-1274, doi:10.2166/ws.2015.092.

Chunyang H., Peijun S., Jin C., Xiaobing L., Yaozhong P., Jing L., Yuechen L. and Jinggang L. 2005 Developing land use scenario dynamics model by the integration of system dynamics model and cellular automata model. Science in China Ser. D Earth Sciences 2005 Vol.48 No.11 1979—1989.

Davis C., and Farrely M. 2009 Demonstration Projects: Case Studies from South East Queensland, Australia. (Payne Road; Rocks Riverside Park; and Coomera Waters), National Urban Water Governance Program, MONASH Universtit.

Defra Market Transformation Programme (DMTP). 2011. BNWAT05: Rainwater & greywater systems - Supplementary briefing note.

Haase D. and Schwarz N. 2009 Simulation Models on Human–Nature Interactions in Urban Landscapes: A Review Including Spatial Economics, System Dynamics, Cellular Automata and Agent-based Approaches. Living Rev. Landscape Res., 3 (2009), 2.

Han J., Hayashi Y., Cao X. and Imura H. 2009 Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China. Landscape and Urban Planning, 91, 133–141.

Kaparos, G. 2014. Hydropolis project report 4.2.1: Life cycle cost.

Koutiva I., Gerakopoulou P. , Makropoulos C., and Vernardakis C. 2016 Exploration of domestic water demand attitudes using qualitative and quantitative social research methods, Urban Water Journal. DOI:10.1080/1573062X.2015.1135968.

Koutiva I. and Makropoulos C. 2016 Modelling domestic water demand: an agent based approach. Environmental Modelling & Software. Issue: Volume 79, Pages 35–54.

Makropoulos C.K., Natsis K., Liu S., Mittas K. and Butler D. 2008 Decision Support for Sustainable Option Selection in Integrated Urban Water Management, Environmental Modelling and Software, 23, 12, pp. 1448-1460.

Mooy R., Langley D. and Klok J. 2004 The ACMI Adoption Model – prediction the diffusion of innovations. International System Dynamics Conference, Oxford, England, July 25-29, 2004.

Nolde E. 2007 Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces, Desalination 215, pp. 1–11.

Lee M., Tansel B. and Balbin M. 2011 Influence of residential water use efficiency measures on household water demand: A four year longitudinal study, Resources, Conservation and Recycling 56, pp. 1-6, doi:10.1016/j.resconrec.2011.08.006.

Mann L. 1989 Becoming a better decision maker. Australian Psychologist 24 (2): 141–155. doi:10.1080/00050068908259558.

Paris. S. and Schlapp C. 2010 Greywater recycling in Vietnam — Application of the HUBER MBR process, Desalination 250, pp. 1027–1030.13.

Rosegrant M.W., Cai. X. and Cline S. 2002 World Water and Food to 2025, International Food Policy Institute, Washington, D.C., p. 5.

Rozos E., Makropoulos C. and Maksimovic C. 2013 Rethinking urban areas: an example of an integrated blue-green approach, Water Science and Technology: Water Supply, 13 (6), 1534–1542, doi:10.2166/ws.2013.140.

Rozos E. and Makropoulos C. 2013 Source to tap urban water cycle modelling. Environ. Model. Softw. 41, 139–150.doi:10.1016/j.envsoft.2012.11.015

Rozos E. and Makropoulos C. 2012 Assessing the combined benefits of water recycling technologies by modelling the total urban water cycle. Urban Water J. 9(1), 1 - 10. doi:10.1080/1573062X.2011.630096.

Saltelli A. and Annoni P. 2010 How to avoid a perfunctory sensitivity analysis. Environmental Modelling and Software 25, 1508e1517.

Sterman J.D. 2000 Business Dynamics Systems Thinking and Modeling for a Complex World, McGfaw-Hill, ISBN 0-07-231135-5.

Styles M. and Keating T. 2000 Water Efficient Schools Chesswood Middle School Project, Final Project Report, October 2000.

Vernardakis, C. 2013. Hydropolis project report 4.1.1: Survey on alternative water sources for household uses.

Vorosmarty C.J., Green P., Salisbury J. and Lammers R.B. 2000 Global water resources: Vulnerability from climate change and population growth. Science, 2895477, 284–288.

Xenos D., Passios I., Georgiades S., Parlis E. and Koutsoyiannis D. 2002 Water demand management and the Athens water supply, Proceedings of the 7th BNAWQ Scientific and Practical Conference "Water Quality Technologies and Management in Bulgaria", Sofia, 44–50, Bulgarian National Association on Water Quality.