Agent-Based Modeling to Estimate Residential Water Demand and to Explore Optimal Demand Side Water Management strategies

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1 Introduction

The continuously intensifying scarcity of water resources is a crucial problem in almost all contemporary societies. The traditional methods emphasize increasing water supplies, but do not consider water consumption reduction. However, under the scarcity of water resources and financial constraints, promoting people awareness toward water consumption reduction, changing the habits of water using, and improving water using efficiency should be taken into account.

Demand management paradigm has been emerged to influence and reshape demand by mechanisms such as metering, initiatives such as water recycling and the promotion of water-saving technologies. However, studies on the role of social networks and non-tariff-based techniques for water conservation are in their infancy (Rixon, A. and Burn, 2002).

This work aims in develop an Agent-Based Model (ABM) to capturing the complex interaction between water stakeholders for estimation of residential water demand and exploring an optimum demand side water management strategy. The model is composed of an interacting consumers, water supplier, and policy maker agents. The model also introduce an inter agent communication to simulate the dynamic behavior of actual consumers through an influence diffusion mechanism.

The model can simulates the residential water demand–supply chain and analyze impacts of the factors on residential water consumption. It can be used for choosing the cost effective urban water management strategy. It also provides the policy makers with a useful tool to evaluate water price policies and non-tariff based techniques for water conservation in different scenarios. The model development was done using C++ programming language.

Semi-hypothetical tests of the model have been done to determine the residential water consumption and assess the performance of alternative demand side management policy instruments in terms of their effectiveness in reducing aggregate demand and their distribution implication.

2 Literature Review

2.1 Demand Management

Demand management practices are the key issue for shifting the orientation of urban water policy towards more sustainable direction. It requires integration of engineering, environment as well as socio-economic aspects of water management. Traditionally, municipal water utilities have been taking a reactive approach to providing adequate supplies to meet the needs of residential, industrial, and other water users. Increased demand typically has been met via construction of new plants and the establishment of new sources of supply. However, Demand management should involve a broad range of measures that aim to increase the efficiency of water use. These can include:

- Conservation-oriented tariff structures
- Public awareness campaigns
- Pressure management and leak reduction programs
- Water audits
- Water saving and reuse technologies.

The effectiveness of demand management policy instruments in increasing efficiency and their equity implications for residential users is debating issue among economist and policy makers (E.Renwick, M. and S. O. Archibald, 1998). For example economist generally advocate higher water price as means of demand management option, others argue the non-price policies which directly controls residential water use are the only viable means to reduce water demand. For example Arbués, et al. (2003) suggest water price as the main instrument to control demand. All demand management activities will directly or indirectly affect consumers and hence a public awareness campaign will play an important role in any DM programme (Vairavamoorthy and Mansoor , 2007).

According to E.Renwick, M. and S. O. Archibald, (1998) the problem facing policymakers and water utility managers is a lack of adequate information and appropriate tool to determine the performance of price and non-price policy instrument. This suggests the need for develop new methodology and appropriate tools that can capture the impact of different demand management instruments in reducing the consumption water. Moreover, the decision making process in urban water management should include all water stakeholders. The coordination between various water agencies and enforcement bodies has major advantage in planning an effective water conservation policy. It also promotes decentralization and participation of stakeholders so as to broaden role of the civil society in water management as water demand management strategies.

In recent years it has also become increasingly evident that the human dimension plays a key role in resources management (Pahl-Wostl, C. and M. Hare, 2004). Ensuring communication and exchange of information and knowledge is a decisive factor for providing enduring and socially approvable solutions. These demand the focuses of demand management policies towards the improvement of social influence in reducing the consumption in residential areas. Social modeling in water demand management was taken in to account in a new approach that simulate the diffusion of information through the interaction between water consumers.

Thus, determining the optimal water demand management policy should implement an appropriate modeling tool and methodology which can simulate the dynamic interactions between all water stakeholders. E.Renwick, M. and S. O. Archibald, (1998) highlight the advantage of Agent based modeling approach over the other equation based approaches in building dynamic interactions of the real world. Moss, *et al.*, (2001) also propose, agent-based social simulation supports a methodology that itself provides a suitable framework for collecting observations of the social and physical systems, to identify relationships and processes. ABM, due to their inherent characteristics, can be effectively used to model both the dynamics and the complexity of water demand management.Therefore, in this work an Agent based modeling tool is developed and applied for exploring optimal demand side management strategy.

2.2 Agent Based Modeling

Agent-based modeling (ABM) is a powerful simulation modeling technique that has seen a number of applications in the last few years, including applications to real-world problems. It competes with equation-based approaches in many disciplines. According to Parunak *et al.*, (1998) the forms of the model and the way how it executes are the major differences in Agent based and equation based approach. In agent-based modeling, the model consists of a set of agents that encapsulate the behaviors of the various individuals that make up the system, and execution consists of emulating these behaviors. However in equation-based modeling (EBM), the model is a set of equations, and execution consists of evaluating them.

In real world, there are many systems that are too complex and large to be captures by a single agent. So Minjie Xu a, *et al.*, (2008) suggested that with a multi-agent modeling approach it is possible to deal with entities at different range of complexity and unity. Multi-Agent Systems comprise multiple agents, which interact among themselves or with objects in their environment, having a limited viewpoint and in the absence of a system global control point. It tries to represent complex systems by defining the involved entities (individual or collective) and by formulating their behaviour and interaction in the specific environment.

The fundamental idea behind agent-based models is that decision making distributed among autonomous actors, which either operate individually or may communicate and (Laine, 2006). ABMs have multiple applications but we are particularly interested in modeling the dynamic interaction between water stakeholders to determine the residential water demand. Water consumer agent (CA), water supplier agent (WSA) and policy maker agent (PMA) are used to represent the interacting water stakeholders.

2.3 Agent Based Models for Water Management

Agent-based models have successfully been used to water management problems, thus, showing the great potential for future decision support development. Consider the FIRMA (Freshwater Integrated Resource Management with Agents) project, where an agent based model is used for the simulation of physical, hydrological, social and economic aspects of water resource management. It improves on existing integrated assessments by explicitly representing customers, suppliers, and government and their interaction at various levels of aggregation. FIRMA yield insights into the social processes of water management, leading to the consideration of a wider range of aspects of the environment in decision making. FIRMA is a decision support tool for the integrated design of water management.

The other example is DAWN, a software tool for evaluating water-pricing policies, where a multi-agent system is implemented to simulate the residential water demand-supply chain. An agent community is assigned to behave as water consumers, while econometric and social models are incorporated into them for estimating water consumption. DAWN's main advantage is that it supports social interaction between consumers, through an influence diffusion mechanism, implemented via inter-agent communication (Athanasiadis, et al. 2004). It enables the design, creation, modification and execution of different scenarios for policy making.

Rixon and Burn, (2002) formulates agent-based models to investigate the effects of social networks, and tariff structures, technology adoption and water use behavior on water conservation. The model output shows social networks result in a significant reduction in simulated water use under the variable tariff regime and this suggests that within small communities where social cohesion is strong, there is ability for non-tariff-based strategies to successfully impact on water use.

In this work, we adopt an agent based approach to dealing with the complexities derived from multiple factors which influence the domestic water consumption. This paper also describes the development and application of a simple agent-based model to explore the effects of social networks and tariff structures on water use behaviour.

3 ABM Formulation for Residential Water Demand

3.1 Residential Demand Forecast Model

According to Kolokytha, *et al.* (2002) the investigation of the determination of the residential water demand is a prerequisite for any demand-driven water policy design. For estimating residential water demand, a variety of methods and econometric models have been used on the basis of the nature and availability of data.

Water demand estimation is usually formulated as a generic model of form
$Q = f(P, H)$ which relates water demand Q to water prices P and family attribute H.

Econometric model used for estimation of residential water demand is:
$Q_{(i,t)} = a + bP_{(i,t)} + cH_{(i)} + \xi_{(i,t)}$ .... (1)

Where

- $Q_{(i,t)}$ *is the water consumption in cubic meters for household i at time t ;*
- $P_{(i,t)}$ *is the vector of price variables;*
- $H_{(i)}$ *is a vector of community-specific variables;*
- a, *b, c are coefficients to be estimated (elasticities);*
- $\xi_{(i,t)}$ *is the error term.*

3.2 Social model

In the water demand supply chain all area consumer society interacts with each other. To simulate this social interaction we adopt the mechanism used by (Athanasiadis, et al. 2005).

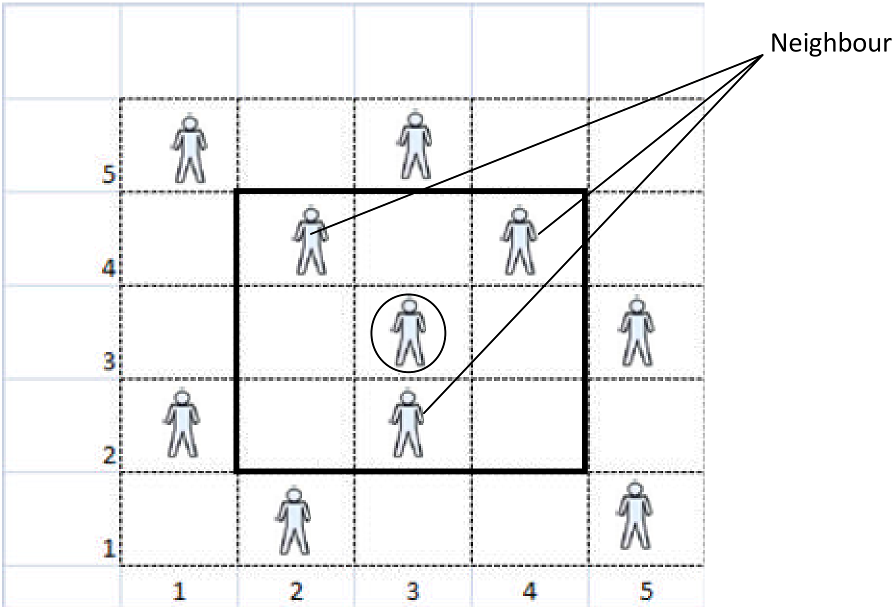

Figure 1. Social Grid

A 2-D social grid shown in Figure 1 is used to simulate the society of consumer agent (CA), whose communication represents social relationship among them. Each CA is determined by its position on the social grid. So, a single CA is define as CA(x, y), where x, and y are its coordinates on the grid. The social interaction between CAs is limited to neighborhood. As an example consider CA (3, 3) in Figure 1 shown above. Let the neighborhood scope is limited to 1, and the neighborhood area of CA (3, 3) is marked out by the square frame. As the figure demonstrate the water consumption of CA (3, 3) is affected only by its three neighbors CA (2, 4), CA (3, 2) and CA (4, 4). The neighboring agents communicate their Social Wight (*Sw*) that represents their ability to persuade.

Consumers' ability to change their water demand depends not only on the influence of neighbors but also on consumers own attitude to reduce water consumption (comprehending ability). The social function is, therefore, defined as a function of promoting ability of neighbors and comprehending ability of consumers.

$S_{(i,t)} = f\,(Cw\,,\ \sum_{1}^{ni} Sw_{ij})$ ....(2)

Where

- $S_{(i,t)}$ *is the social variables of* CA_i *at time t,*
- Sw_{ij} *is the social weights that consumer agent CAi receives from its neighbour j, it deepens on neighbours' ability to promote conservation signal;*

- *n_i is the number of neighbours of CA_i.*
- *Cw is a function for adjusting the sum of social weights, and it represents a consumers' ability to comprehend water conservation signals.*

In this model the analysis of the extent to which price policies, non price demand management scenarios and their combination reduce residential water consumption is done through scenario evaluation. The economic model is then implemented in the code to evaluate the influence of alternative DSM policy instruments (such as water saving technology, public education) and increasing block pricing schedules.

In order to consider the social influence the modified econometric model $Q= f(P, H, S)$, which is suggested by Athanasiadis, et al. (2005) is used.

$$Q_{(i,t)} = a + bP_{(i,t)} + cH_{(i)} + dS_{(i,t)} + \xi_{(i,t)} \quad (3)$$

Where $S_{(i,t)}$ is the vector of social attribute variables,

4 ABM Structure

In agent based modeling of residential water demand the systems that needs to be analyzed and modeled are more complex in terms of their interdependencies (Macal, C. M. and M. J. North, 2005). The structure of this multi-agent based model includes three kinds of agents: water consumer agent (CA), water supplier agent (WSA) and policy maker agent (PMA).

4.1 Agent Role

Consumer Agent

CA plays the major role in the simulation. It encapsulates the dynamic behavior for area residents who consume water and pick up its cost. This agent also send complain to PMA if they are not happy with the water tariff and unable to get basic consumption due to the price placed on water usage.
The actual consumers interact with each other and this social activity is one of the major factors which affect water consumption behavior. Thus, in this study a social interaction model is incorporated to define the dynamic consumer behavior.

CA communicates with neighbors to propagate demand management and price policy. In this model the influence of the neighbors' over the consumers' attitude is reflected through social weight. The influence mechanism is shown in sec 3.2:

Water Supply Agent

WSA advise water price to PMA according to its benefit. This agent is responsible for collecting CAs` consumption and calculates the total demand. WSA also complain to PMA if they lose their revenue and maximum consumption is exceeded.

Policy Maker Agent

The fundamental decisions, like the determination of investments in water sector and water tariff structures, have been strongly influenced by administrative rationale (Arbués, et al. 2003). Furthermore, in water management strategy, demand analysis is a precondition of designing an optimum socioeconomic water use and the respective water price. In this model setup PMA enact price policy depending on the information received from the CAs` and WSA at different time steps and revise it in timely fashion.

4.2 Agent Based Model Simulation Modules

This Agent based model is developed under consideration of multiple interacting agents such as consumers, water suppliers and policy makers. At each simulation step the agents interact at different level to determine the appropriate tariff structure and demand management strategy.
The developed Agent Based Model is used to improve the understanding of how different demand side water management policies are expected to influence consumption of different classes of residential household. This model is composed of two large modules having independent tasks: Tariff Structure Simulation and Scenario Evaluation.

Tariff Structure Simulation

The first module is constructed in the model to determine the suitable price block structure. In this module consumer, water supplier and policy maker agents interact at each simulation step to determine appropriate tariff structure. The interaction between all agents is mediated by policy maker. At each step the policy maker receive information from all consumers and suppliers to decide on the modification of the tariff structure (i.e. an increment or reduction of unit prices).

In this model setup a three-block initial tariff structure is implemented as an input. The first block price is for satisfying the basic consumption need of consumers and the tariff related to this block is set to remain same at different time of simulation and interaction. The other two price blocks however, will be varied during simulation based on the information received through the interaction of consumer, supplier and policy maker agents. The policy makers' agent varies the tariffs until it converges to a point where consumer and supplier agents accept the modified tariff structure.

Scenario Evaluation

The ultimate effect of the demand side management policies depend on the policy instrument selected and the composition of aggregate demand .The extent to which a particular police instrument reduces aggregate demand equals the sum of the saving from individual households.

The scenario evaluation module of this agent based model examine an alternative demand side water conservation policy instruments such as conservation-oriented tariff structures, social network/ Public awareness campaigns, water reuse and saving technologies etc...

The social influence is one of the key drivers on water use behavior of consumers and needs further detail studies. This module of the model is also constructed in such a way that it can capture the actual dynamic behavior of consumers and the diffusion of social influence within the consumer agents.

The simulation of this module is performed under any initial input tariff structure and other demand management scenarios with different policy review schedules to evaluation and chose the most effective one.

4.3 Model Simulation procedure

Tariff Structure Simulation Steps

The model simulate the interaction of consumer, water supplier and policy maker agents to suggest suitable tariff structure and determine residential water demand. An abstract description of the model simulation procedure involves the following steps:

1. Users prepare the initial input parameters such as water demand econometric model, population size and growth rate, neighborhood limit etc..
2. WSA initialize water tariff structure.
3. PMA enact the price and inform both WSA and CAs.
4. CA receives price information, and communicates with its neighbors according to the social influence mechanism.
5. Each CA estimates its own water demand. This step takes in to account consumer agent communication with each other.
6. CA reports its water demand to WSA and any complain to PMA.
7. WSA collects all residents' demands, calculates the total consumption, total costs, and reports the results to PMA.
8. PMA adjusts the price block structure if needed, turn to step 2.
9. When the iteration is over, the model present, revised block tariff structure and the residential consumption.

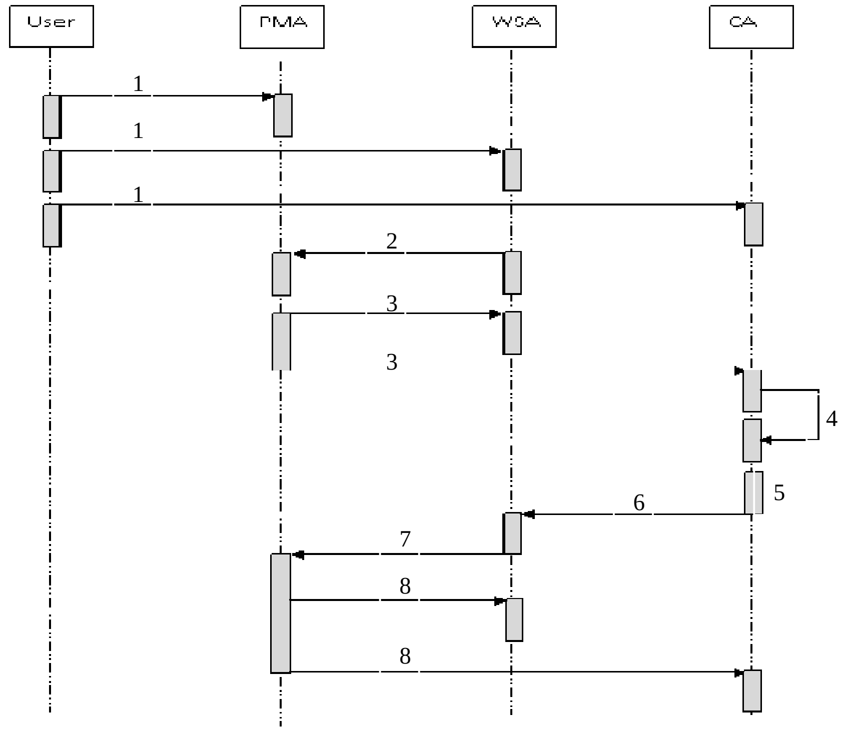

Figure 2. *Showing the procedure of tariff structure simulation*

Scenario Evaluation Steps

After the tariff structure iteration is performed the model simulates the residential water demand supply chain to determine an optimum demand side water management scenario. The steps include:

1. *Initialization and Scenario input*
   Users prepare the simulation scenario by specifying a set of parameters for the demand side management policy instruments. This include simulation duration, simulation step, demand management scenario to be simulated and policy review steps.
2. *Model Simulation*
   The model simulates the scenario entered by the users. During simulation all autonomous agents interact to determine the residential consumption within the time step. Each step simulate a time interval, during which water consumption is estimated
3. *Result*
   When the simulation duration is over, the results such as total and individual consumptions are presented to the user.
4. *Scenario Evaluation*
   The model Scenario results are then evaluated by the user. From different simulation result uses can make a possible comparison to make a decision on the optimum demand side management strategy.

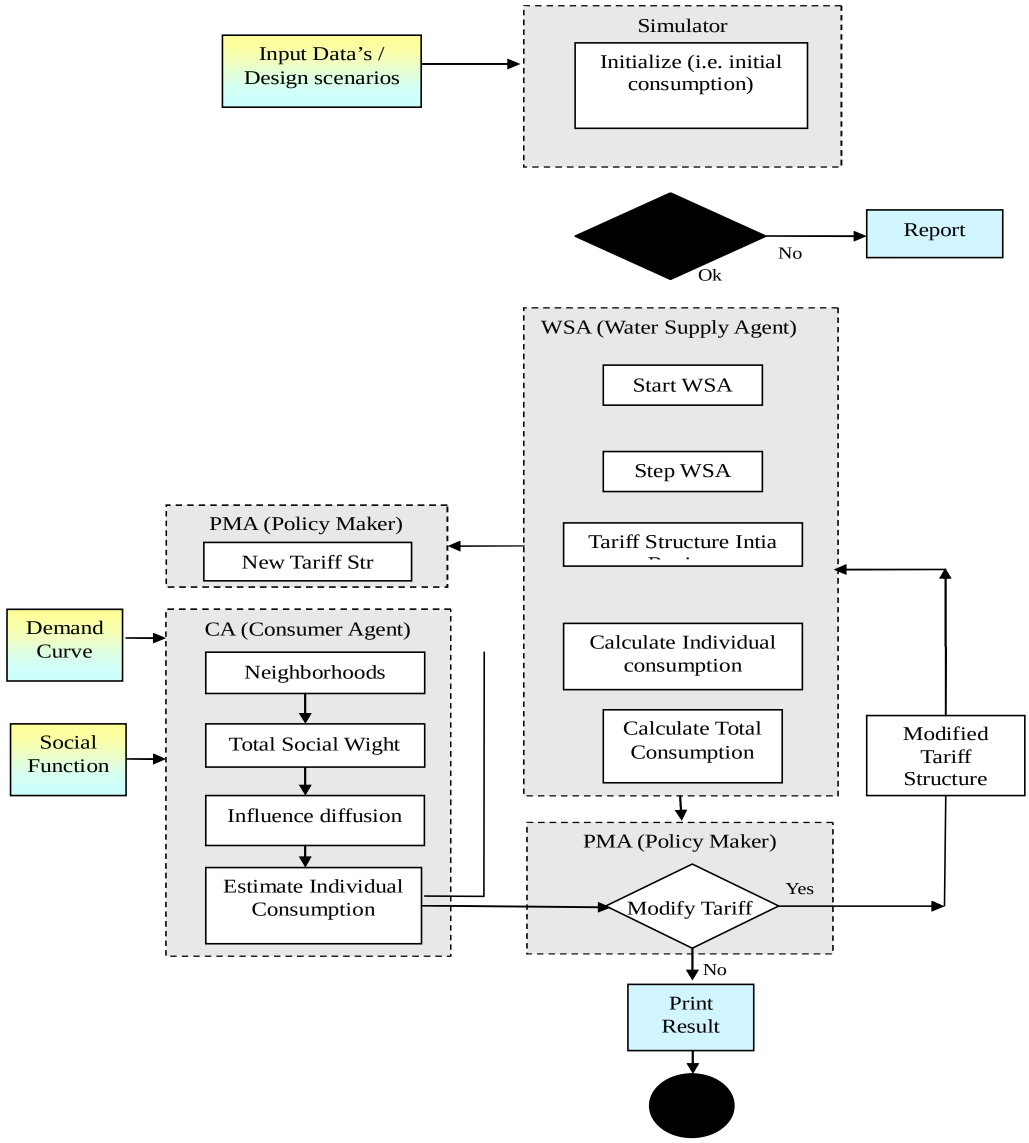

Figure 3. An Agent Based computational framework for simulating agent interaction

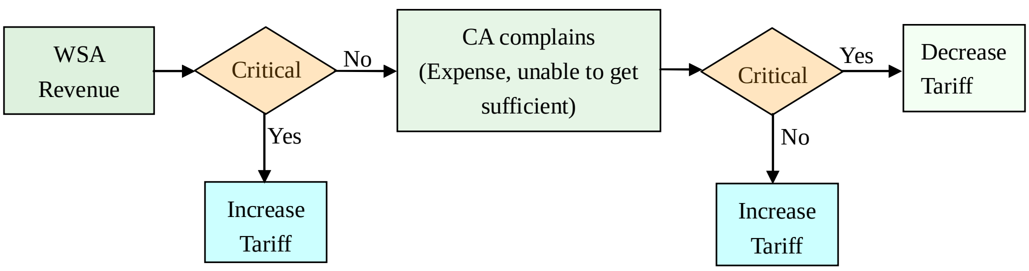

Figure 4. Showing the algorithm for price revision

5 Required Model Input Data and Output Files

5.1 Model Input Data

In order to run this agent based model, some of initial input data's have to be saved in a single folder called ***Data*** priors to simulation. These input parameters and their descriptions are shown bellow in the next sub topics.

5.1.1 Demand Curve

The determination of the residential water demand pattern is a prerequisite for demand driven water policy design. Individual water utilities must obtain demand curve estimates for their own service areas, and use them to simulate the effects of expected changes in demographic and other conditions, as well as price (Olmstead, S. M. and Stavins, R. N. 2007).

The demand curve is an input for the estimation of residential water consumption and scenario evaluation. Thus, prior to execution of the model users have to generate the demand curve from residential water consumption data. An urban residential water demand curve might explain demand as a function of price, household income, family size, home and lot size, weather, and possibly other variables.

The file name which is used for the demand curve in this model setup is ***demandcurve.txt*** and should be saved in the ***Data*** folder of the model project. Demand as a function of price generated by Mylopoulos, *et al*. (2004) is adopted for this hypothetical test. It has a functional form as shown below:

$$lnQ = a(lnP) + b(lnP)^2 + b(lnP)^3 + k$$

*Table 5:1. Sample input demand curve (**.txt** file).*

0.2 ---------> *a*
-0.356 -----> *b*
-0.5---------> *c*
4.3----------> *k*

Where a, b and c are coefficents.

5.1.2 Supply Curve

Two of the principal factors affecting water supply costs and gross margin are the amount of water produced and the source of the water. Some of the most important cost components which associated with these are capital cost, treatment cost, electricity and maintenance cost (Atikol, U. and Aybar, H. S. 2005).

In this model any type of supply patter can be implemented to simulates the residential water demand–supply chain and analyze impacts of the factors on residential water consumption. This curve shows relation between quantities produced as a function of price. The file name which is used for the supply pattern is ***supplycurve.txt*** and it should be saved in the ***Data*** folder of the model project.

Table below shows the coefficients for hypothetical supply curve which has a form $Q_s = aP+k$, *where p is unit price variale.*

*Table 5:2. Sample input supply curve (**.txt** file)*

```
10---------> a
7.5----------> k
```

5.1.3 Social Function

In addition to meeting consumers demand, water strategies generally have to discourage reckless waste by encouraging a 'wise use' attitude. Calls for the public to save water over many years have made them value water and become very conservation conscious.

A recorded questionnaires data about consumers' interaction and motives to conserve water, and direct observations data of individual water consumption reduction due to implementation of water conservation education/campaign are used to generate social model. This social function is then used as an input for our model.

In this model consumer agents clustered in **four** types based on their ability to promote and comprehend water conserving information.

Consumer Type

This work adopts the result from the survey data in the city of Thessaloniki, Greece by Kolokytha, *et al*. (2002). Consumer agents are clustered in four types based on their ability to promote and comprehend water conserving information

Table 5:3. Consumer type

Consumer Type		**Ability to promote**	**Ability to Comprehend**
A	Opinion Leaders	High	Low
B	Socially apathetic	None	None
C	Opinion seekers	Low	High
D	Opinion receivers	Low	Low

According to their ability to promote water conservation signals:

Type A: Opinion leaders are promoters of the conservation signals and supposed to influence their neighbors. They have high ability to promote.
Type B: Socially apathetic, insensitive to social issues and don't promote water saving signals
Type C: Opinion seekers; are socially sensitive but have low ability to promote water conservation signals.
Type D: Opinion receivers; are average consumers who have low ability to promote water conservation signals.

According to their ability to comprehend water conservation signals:

Type A: Opinion leaders, are supposed to be environmental aware; their ability to further lower their water consumption is generally limited.
Type B: Socially apathetic, are indifferent to public awareness campaigns and have a negative attitude about conservation.
Type C: Opinion seekers; are opinion followers who are willing to revise their water demand. They can be easily influenced by families through their social relations with opinion leaders.
Type D: Opinion receivers, their attitude is passive and need considerable pressure by their contacts to start changing their habits of water consumption.

The percentage of each consumer type and different social weight associated with their ability to comprehend and promote water conservation signals have to be provided as an input (***.txt)*** file and saved in the ***Data*** folder of the model project.

Note: Model simulation can be triggered once the above necessary input data are prepared. However, additional input data's should be provided on MSDOS window during execution. These data's include: population size, growth rate, new tariff structure (if required), simulation duration, simulation step, demand management scenario to be simulated and policy review steps.

5.2 Model Output Files

Once the necessary input data files are created, the model perform the simulation and results will be recorded in a series of files stored in folder name **Data**. All the output files are in an **Excel** format, so they can be reprocessed with any word processor or spreadsheet software. Some of the output files are shown in Appendix A.

6 Model Application and Hypothetical Test

6.1 Data's Used

Residential Consumption and Supply Pattern

In this study a cubic price functional form of water demand curve developed by Mylopoulos, et al. (2004) is used to estimate the residential water consumption.

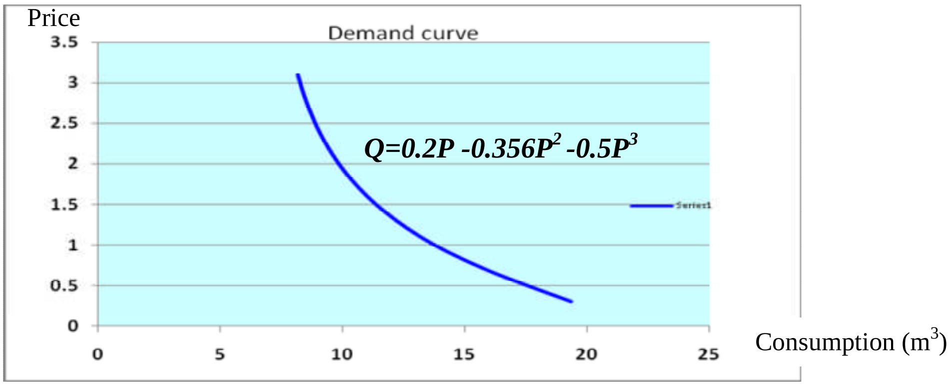

Figure 5. Demand Curve

The amount of water treated and supplied by water authorities affects its unit price value. In this hypothetical test a curve $Q_{supply} = 10P+7.5$ *is* used to represent the supply pattern by the water utilities.

Social Data

The social weight has to be assigned to consumers based on their ability to promote and comprehend water conserving. However due to lack of these information's we use an arbitrary social data and function shown below.

Table 6:1. Social weight based on neighbors' ability to promote water conservation signal (Sw_{ij})

Consumers	Relative Weight	Normalized
A. Opinion Leader	3W	1
B. Opinion Receiver	2W	2/3
C. Opinion Seeker	1W	1/3
D. Socially Apathetic	0W	0

Table 6:2. Social weight based on consumer ability to comprehend water conservation signal (Cw_i)

Consumers	Weight	Normalized
A. Opinion Leader	4	0.27
B. Opinion Receiver	7	0.88
C. Opinion Seeker	10	0.99
D. Socially Apathetic	1	0.02

The normalized weight value in *Table 6:2* , based on the ability to comprehend, is used as a modifying factor for the consumption reduction due to social influence of neighbors. Therefore, in this semi hypothetical test, the social function is defined randomly as: $S_{(i, t)} = -0.2(1+Cw_i) \sum Sw_{ij}$.

Experiment Simulation Scenarios

The scenarios can address a broad range of options to explore an optimum demand management strategy. In this hypothetical test, the model was used to evaluate four scenarios, which are as follows:

- Scenario 1: Water price is adjusted to the real price, without considering the public social educations. (Assumed inflation 5%)
- Scenario 2: Water price is increased by 10%, without considering the public social educations.
- Scenario 3: Water price is adjusted to the real price, considering the public social educations, with the implementation of education or other information policy.
- Scenario 4: Water price is increased by 10%, considering the public social educations, with the implementation of education or other information policy.

Tariff Structure

In this hypothetical example an increasing initial block tariff structure is used to formulate water conservation scenarios.

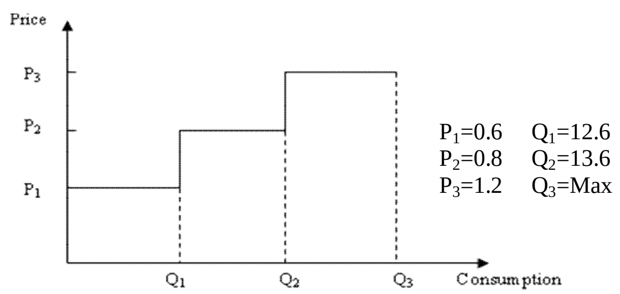

Figure 6. Initial tariff structure

The first block price is for satisfying the basic consumption need and is set to remain same at different time of simulation. However, during scenario evaluation stage users has the option to choose either tariff structure which is proposed by the model or any other new tariff structure.

Miscellaneous data

For this hypothetical test a population size of 1200 is arbitrarily chosen with a population growth of 0.9. The simulation duration of four years with a simulation step of one month is used to evaluate different water conservation scenarios. Users are also required to supply policy review stage. For this example water policy review is performed every one year.

6.2 Results

Tariff iteration outputs

During each tariff iteration step the policy maker agent receives information from both water supply and consumer agents and enacts the price tariff if necessary. Figure 7 shows the variation of price values during agent interaction to determine an appropriate water tariff.

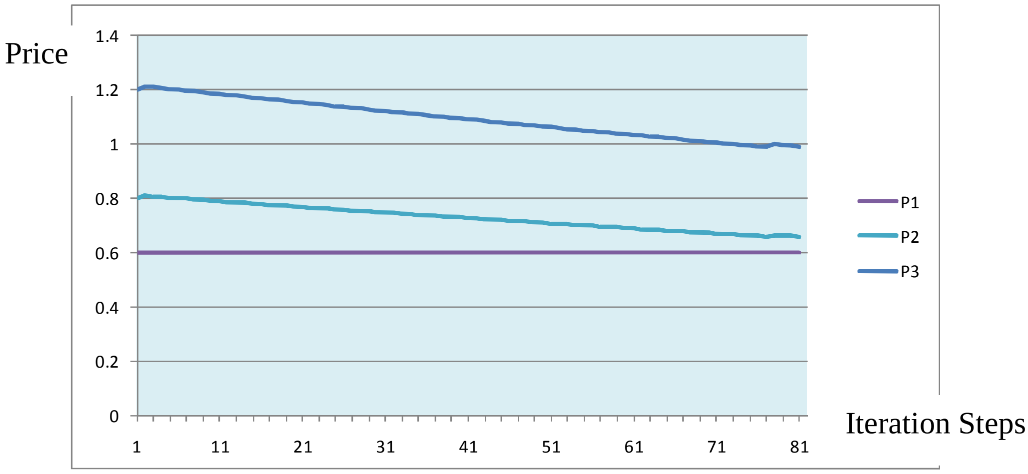

Figure 7. Price variation

Based on the response of all interacting agents, the model suggested the price tariff structure shown in Figure 8 below. This modified price block can be used as an input for scenario evaluation step. However, users have the right to choose different input tariff structure for evaluating water conservation options.

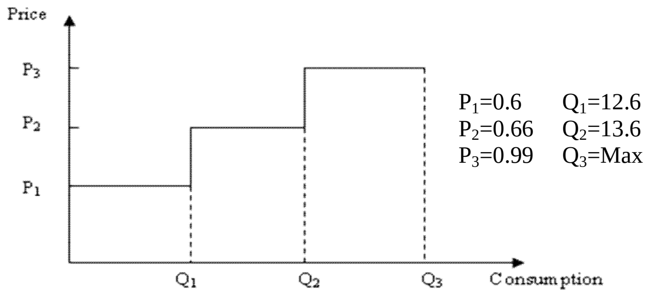

Figure 8. Suggested tariff structure

Scenario evaluation output

Adopting the suggested tariff structure as an input the following results are obtained from four scenarios.

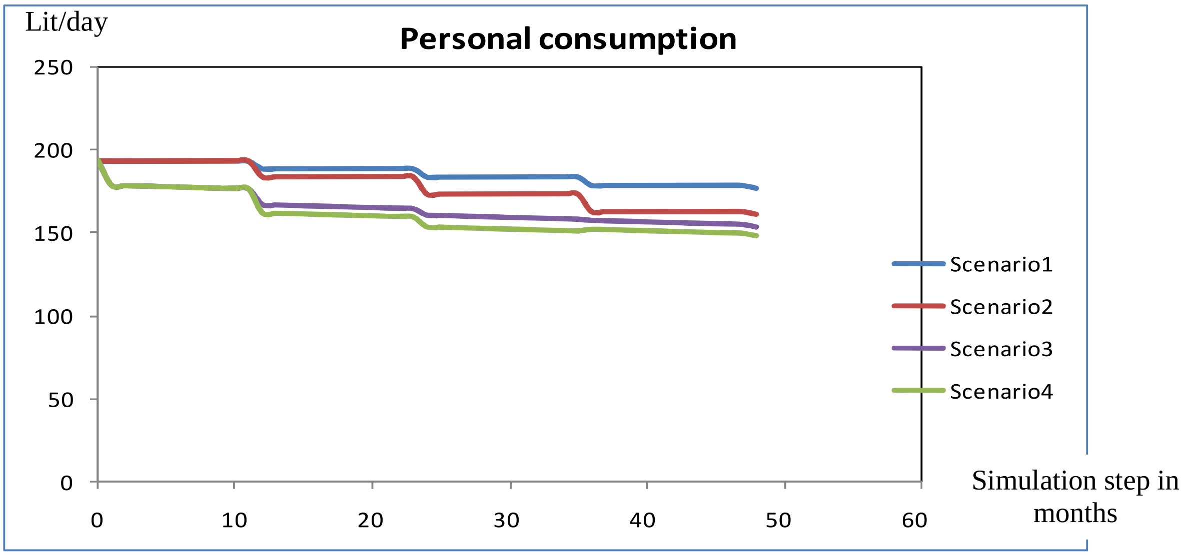

Figure 9. Personal consumption

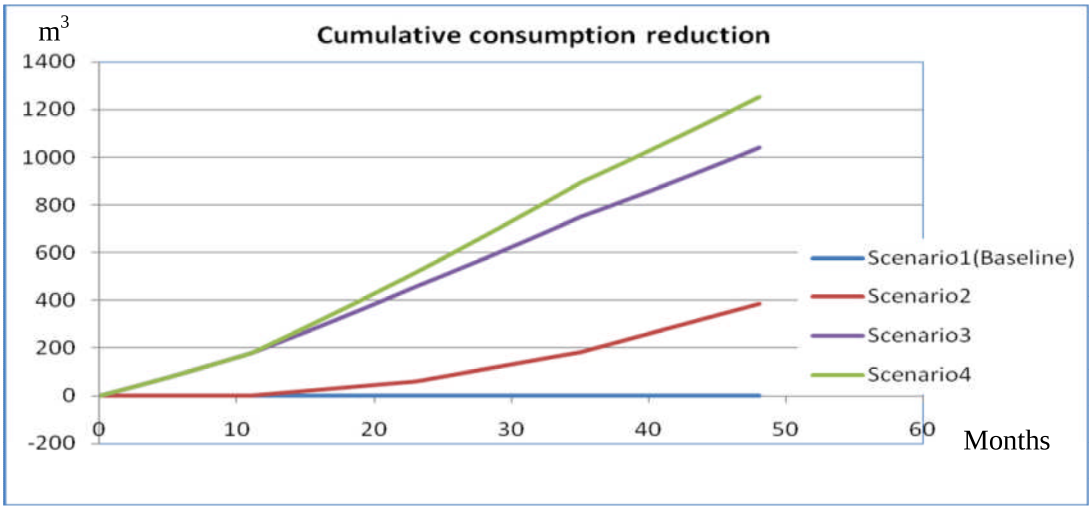

Figure 10. Comparison of personal water consumption reduced (from base year)

Figure 9 clearly shows the reduction of percapita consumption under the implementation of different demand management options. However the evaluation and comparison of different scenarios (i.e. Figure 10) shows that the amount reduced by implementing scenario 2, scenario 3 and scenario 4 is about 8.7%, 9.2% and 16.2 % respectively when compared to senario1 at the end of simulation (four year).

Interestingly, scenario 4 on Figure 9 shows an initial reduction of consumption followed by a small increment after simulation duration of 36 months. This is because the consumption reduction by some consumers gives an opportunity to reduce their expense. Thus, the reduction in expense allows some consumers to shift from small consumption to large consumption block which in turn increase the average percapita consumption.

7 Conclusion and Recommendations

In this work we develop an Agent Based Model for estimation of residential water demand under different water management strategies. This Agent based model captures and shows the pattern of residential consumption and how it is changing with the change in behavior of consumers as a result of different decisions (such as change in water tariff structure, implementation of public awareness/education) made by autonomous body such as water utilities or regulators. The model emulates the real social interaction within consumers and gives an opportunity to explore the effect of information-diffusion in reducing residential water demand. Thus, it can be used effectively by decision makers to evaluate different water conservation scenarios and chose an optimum demand side management strategy. In addition to evaluate different water conservation scenarios, the model is used to suggesting the water tariff structure that is appropriate for both water consumers and supply authorities. This offer further opportunity for regulators to monitor the tariff structure set by water utilities.

Demand side management involve a broad range of measures that aim to increase the efficiency of water use but due to limitation of time and lack of information/data, only the major water conservation instruments such tariff structures and social influence (public awareness/information diffusion) are implemented. However, the developed tool is an open source code that allows coupling with existing models and further extension to include different demand management instruments if required.

Therefore, the developed model is a generic Agent Based Model tool that can encapsulate the dynamic behaviors of all water stakeholders and simulate the complex response patterns of these stakeholders with a view of exploring optimal demand side water management strategies.

Acknowledgment

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References

Arbues, F., Garcia-Valinas, M. ı. A., & Martinez-Espineira, R. 2003. Estimation of residential water demand: a state-of-the-art review. Journal of Socio-Economics, 32 81–102.

Athanasiadis, I. N., Vartalas, P. & Mitkas, P. A. (2004) DAWN: A platform for evaluating water-pricing policies using a software agent society. In: *"Complexity and Integrated Resources Management"*, Germany.

Athanasiadis, I. N., Mentes, A. K., Mitkas, P. A., & Mylopoulos, Y. A. 2005. A Hybrid Agent-Based Model for Estimating ResidentialWater Demand. Paper presented at the Transactions of The Society for Modeling and Simulation International.

Atikol, U. & Aybar, H. S. 2005. Estimation of water production cost in the feasibility analysis of RO systems Desalination and the Environment, 184: 253-258
Kolokytha, E. G., Mylopoulos, Y. A., & Mentes, A. K. 2002. Evaluating demand management aspects of urban water policy—A field survey in the city of Thessaloniki, Greece. Urban Water 4: 391–400.

E.Renwick, M. and S. O. Archibald (1998). Demand side management for residential water use: Who bear the conservation burden? . Land Economics.

K.Vairavamoorthy and M. A. M. Mansoor (2007). Demand Management in Developing Countries.

Laine, T. (2006) AGENT-BASED MODEL SELECTION FRAMEWORK FOR COMPLEX ADAPTIVE SYSTEMS. In: *in Computer Science and Cognitive Science*: Indiana University.

Macal, C. M. & North, M. J. 2005 Tutorial on Agent-Based Modeling and Simulation. Paper presented at the Winter Simulation Conference, Argonne National Laboratory.

Minjie Xu a, b., Hub, Z., Wua, J. & a, Y. Z. (2008) A hybrid society model for simulating residential electricity consumption. *Electrical Power and Energy Systems* **30** 569–574.

Moss, S., Pahl-Wostl, C. & Downing, T. (2001) Agent-based integrated assessment modelling: the example of climate change. **2**: 17–30.

Mylopoulos, Y. A., Mentes, A. K., & Theodossiou, I. 2004. Modeling Residential Water Demand Using Household Data: A Cubic Approach. Water International, Volume 29, Number 1: 105–113.

Olmstead, S. M. & Stavins, R. N. 2007. Managing Water Demand Price vs. Non-Price Conservation Programs: A Pioneer Institute White Paper.

Parunak, H. V. D., Savit, R. & Riolo, R. L. (1998) Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide. In: *Modelling Agent based System*, Paris.

Pahl-Wostl, C. and M. Hare (2004). "Processes of Social Learning in Integrated Resources Management." Journal of Community & Applied Social Psychology **14:** 193–206

Rixon, A. & Burn, S. 2002. Exploring Water Conservation Behaviour Through Participatory Agent-Based Modelling: CSIRO Manufacturing and Infrastructure Technology.

Appendix A

Table A-1. Showing part of tariff structure variation during interaction of all agents

Iteration	P1	P2	P3	Consumers Below Basic (%)	Above Maximum	Cons(m^3)	Supply (m^3)	Suppliers Reaction	Policy Makers Action
1	0.6	0.8	1.2	0	No	7981	5426	Losing Revenue	Increase P
2	0.6	0.81	1.21	0	No	6166	7848	Making Profit	Decrease P
3	0.6	0.81	1.21	0	No	6177	7835	Making Profit	Decrease P
4	0.6	0.8	1.21	0	No	6188	7822	Making Profit	Decrease P
5	0.6	0.8	1.2	0	No	6200	7809	Making Profit	Decrease P
6	0.6	0.8	1.2	0	No	6211	7795	Making Profit	Decrease P
7	0.6	0.8	1.2	0	No	6222	7782	Making Profit	Decrease P
8	0.6	0.79	1.19	0	No	6233	7769	Making Profit	Decrease P
9	0.6	0.79	1.19	0	No	6244	7756	Making Profit	Decrease P
10	0.6	0.79	1.19	0	No	6255	7744	Making Profit	Decrease P
11	0.6	0.79	1.18	0	No	6266	7731	Making Profit	Decrease P
12	.	.	.	.	.	.	.	.	.
13	.	.	.	.	.	.	.	.	.

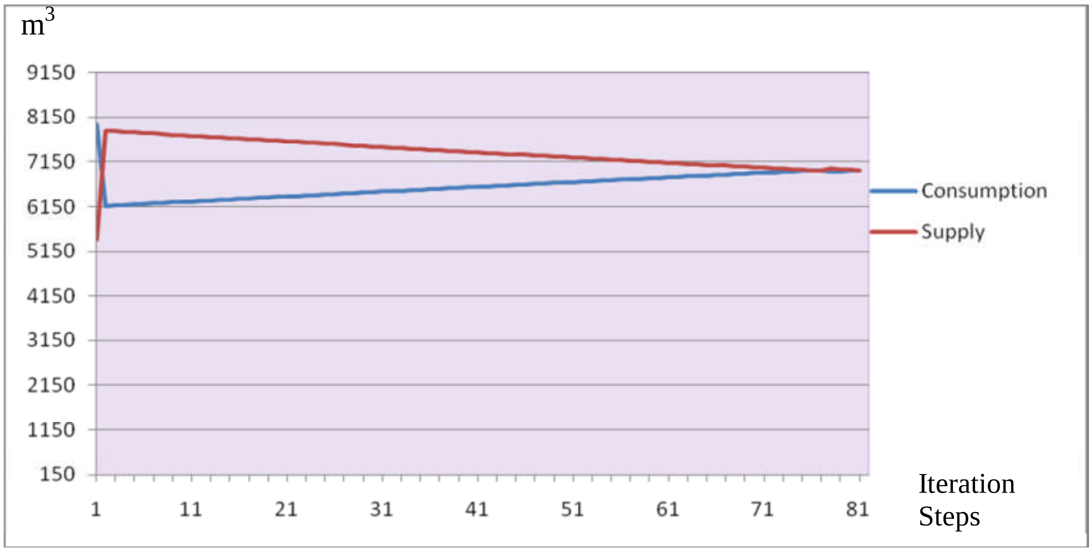

Figure A. Sowing the change in supply pattern and consumption due to policy maker intervention on tariff structure.

Scenario 4 Simulation Outputs

[Water price is increased by 10%, considering the public social educations, with the implementation of education or other information policy]

Table A-2. Showing household consumption reduction due to demand side management strategy

Steps	HH	Total Cons(m3)	Water saved	Cum_Water saved	HH Cons(m^3)
0	400	6957.49	0	0	17.3937
1	400	6413.82	543.667	543.667	16.0345
2	400	6405.78	8.03449	551.702	16.0145
3	400	6397.75	8.03449	559.736	15.9944
4	400	6389.71	8.03449	567.771	15.9743
5	400	6381.68	8.03449	575.805	15.9542
6	400	6373.65	8.03449	583.84	15.9341
7	400	6365.61	8.03449	591.874	15.914
8	400	6357.58	8.03449	599.909	15.8939
9	400	6349.54	8.03449	607.943	15.8739
10	400	6341.51	8.03449	615.978	15.8538
11	400	6333.47	8.03449	624.012	15.8337
12	404	5874.55	458.921	1082.93	14.541
13	404	5866.43	8.11911	1091.05	14.5209

14	404	5858.31	8.11911	1099.17	14.5008
15	404	5850.2	8.11911	1107.29	14.4807
16	404	5842.08	8.11911	1115.41	14.4606
17	404	5833.96	8.11911	1123.53	14.4405
18	404	5825.84	8.11911	1131.65	14.4204
19	404	5817.72	8.11911	1139.77	14.4003
20	404	5809.6	8.11911	1147.89	14.3802
21	404	5801.48	8.11911	1156	14.3601
22	404	5793.36	8.11911	1164.12	14.34
23	404	5785.24	8.11911	1172.24	14.3199
24	408	5623.26	161.984	1334.23	13.7825
25	408	5615.05	8.20465	1342.43	13.7624
26	408	5606.85	8.20465	1350.64	13.7423
27	408	5598.64	8.20465	1358.84	13.7222
28	408	5590.44	8.20465	1367.05	13.7021
29	408	5582.24	8.20465	1375.25	13.682
30	408	5574.03	8.20465	1383.45	13.6618
31	408	5565.83	8.20465	1391.66	13.6417
32	408	5557.62	8.20465	1399.86	13.6216
33	408	5549.42	8.20465	1408.07	13.6015
34	408	5541.21	8.20465	1416.27	13.5814
35	408	5533.01	8.20465	1424.48	13.5613
36	412	5625.83	-92.8249	1331.65	13.6549
37	412	5617.54	8.29019	1339.94	13.6348
38	412	5609.25	8.29019	1348.23	13.6147
39	412	5600.96	8.29019	1356.52	13.5946
40	412	5592.67	8.29019	1364.81	13.5744
41	412	5584.38	8.29019	1373.1	13.5543
42	412	5576.09	8.29019	1381.39	13.5342
43	412	5567.8	8.29019	1389.68	13.5141
44	412	5559.51	8.29019	1397.97	13.494
45	412	5551.22	8.29019	1406.26	13.4738
46	412	5542.93	8.29019	1414.55	13.4537
47	412	5534.64	8.29019	1422.85	13.4336
48	416	5534.64	0	1422.85	13.3044