Chapter 6
An Agent-Based Approach to Support Decision-Making of Total Amount Control for Household Water Consumption

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Introduction

In this chapter, we present an agent-based model of household water consumption simulation (HWCSim) for the visualization of policy effectiveness of total amount control for household water consumption and as a guide for sustainable water resource management. Within this model the volume of household water consumption is regulated through a negotiation process regarding water price adjustment between household and government. Water consumption in an urban area is examined as a closed local water market, and a water price negotiation process between the supply side and the demand side is simulated. This process reflects how the supply side (government) and the demand side (households) reach a consensus on water price.

The world urban population is predicted to reach 5.0 billion in 2030 (United Nations 2007). As a result of massive immigration to urban areas, in the past decade, household-level population activities and environmental influences have become major fields in population-environment research (Sherbinin et al. 2008). People's increasing interest in environmental protection has caused sustainable development to become a popular topic. Sustainable development in this context means that energy supplies are readily available at reasonable cost, but are also sustainable over the long term and can be used for all required tasks without negative social effects (Ibrahim 2010). Water is the most basic resource. No matter how much urban development advances and technology improves, water remains a basic necessity for all life on Earth (Hildering 2004). Despite its importance, the amount of clean water is limited. As reported by the U.S. Geological Survey

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(Gleick 1996), only 0.8% of Earth's water can be considered to be fresh water. Therefore, a serious problem emerges in that, although there is a limited supply of fresh water, the population is increasing sharply. This problem results in a conflict between the water supply side and the water demand side and also results in water shortages.

The quantity of water resources per capita in Japan is half the world average. Tokyo restricted water usage for 42 months, from October 1961 to March 1965 (World Bank Analytical and Advisory Assistance (AAA) Program 2006). The administrative structure in Japan is such that the overall framework for water resource development is set by the national government, whereas actual implementation and management is accomplished at the local level. The national government in Japan implements the Comprehensive National Water Resources Plan (hereinafter, the Water Plan) to manage water resources. This plan is generally implemented every year in order to determine the supply of water and the budget for water supply development. The goal of the administrative structure of Japan is to have the water supply approach the water demand. The national government actually does not play a very large role in local water management; rather, in order to avoid price increases as a result of competition between water users, the government supplies local utilities with significant subsidies (World Bank AAA Program 2006). This leads to relatively low water prices, which may have a negative effect on water conservation. The relatively low price of water determined by local utilities usually does not reflect the exact cost of water. Furthermore, the government incurs a huge cost associated with the water subsidies.

In order to reduce the budgetary burden on the government associated with water supply development, Japan usually subsidizes local water supplies with an appropriate sliding scale, where the subsidies for domestic water use and industrial water use are relatively lower than those for agriculture and sewage treatment. Thus, if the budget for domestic water supply is limited, a balance between water supply and water demand must first be reached. Basically, if the demand can be controlled, then the subsidy for domestic water supply can be better controlled or reduced, for example, through a policy to control the total amount of household water consumption. In this chapter, we suppose that this policy would help the government to coordinate water supply capacity and water demand by affecting personal water consumption.

In order to better evaluate the effectiveness of this policy, we reviewed a number of related studies. These studies can basically be classified into two types. In the first type, researchers analyze the relationships between policies, the location and intensity of urban activities, and urban environmental problems (Alberti 1999; Chin 2002; Ewing 1994, 1997; Neuman 2005). These studies were mainly qualitative and quantitative analyses, which cannot flexibly reflect household decisions. In the second type, the agent-based model (ABM) has proven to be a useful simulation method for reproducing the activity of those who can make their own decisions, and this method has been widely used to reflect the flexible actions of human beings (Fontaine and Rounsevell 2009; Brown et al. 2008; Torrens 2007). Thus, a number of studies have concentrated on simulating the dynamic interactions between household behavior, policy making, and environmental influences (Vlek 2000; Jager and Janssen 2003). These simulations have significantly contributed to the study of behavior–environment interactions and have provided a valuable tool for exploring the effectiveness of policy measures in complex environments (Jager and Mosler 2007).

The goal of this research is to supply governments with the simulation model HWCSim to allow them to visualize the effectiveness of government policies and in this way help governments make policy decisions. In this chapter, we concentrate on domestic water consumption only.

An Agent-Based Approach for Supporting Decision-Making of Local Governments

Local governments are assumed to control the total amount of household water consumption so as not to exceed the threshold determined by local water supply capacity. In order to achieve this target, local governments adjust the price of water in order to regulate household water consumption. In the present research, we construct an HWCSim model that considers households and government to be different agents and simulates their activities as following.

First, initial values will be set for water price and household water consumption. Households will consume water according to these initial values. Then, the government agent will calculate the total amount of household water consumption in each simulation step. If this value exceeds the threshold (as determined by local water supply capacity), then the government will increases the water price in order to reduce the volume of household water consumption. This new price is referred to as the Ask Price. A special process between the government and households is required if the government wants to publish the Ask Price in the term of new policy regarding water price. This process, which in reality is referred to as a public hearing, is referred to herein as the negotiation process. During negotiation, the household side proposes a Bid Price for water according to their willingness to pay (WTP), and the household side will compare the Ask Price with their Bid Price. The comparison results yield differences in household policy attitude. Concretely speaking, if the Ask Price is less than the Bid Price or is greater than the Bid Price but less than the *WTP*, then the policy attitude of the households will be positive. Otherwise, the policy attitude of the households will be negative. After this process, the government will count the number of households that have a positive policy attitude. If more than 50% of the households have a positive policy attitude, then the Ask Price will be implemented as the new water price. Otherwise, the average value of the Bid Price by middle-income households will be set as a new water price. Finally, households will adjust their water consumption according to the new price.

The simulation loop described above will not stop until the government determines a water price that will reduce the total household water consumption to below the threshold. In this chapter, we refer to this water price as the willingness to accept (WTA).

Description of the HWCSim Model

Agent-Based Water Market

In this chapter, like land, water is considered to be a public good. In the HWCSim model, as the entity that controls the local supply of water, the local government is considered to be the supply side of the local water market. Correspondingly, the entity that consumes water is considered to be the demand side of the local water market. However, in the present study, we consider only household water consumption. Therefore, the water market in the HWCSim model is formed by the government (supply side), households (demand side), and the local water resources. In order to better reflect the water market scheme, we referred to research on the land market (Parker and Filatova 2008) and constructed the conceptual water market shown in Fig. 6.1.

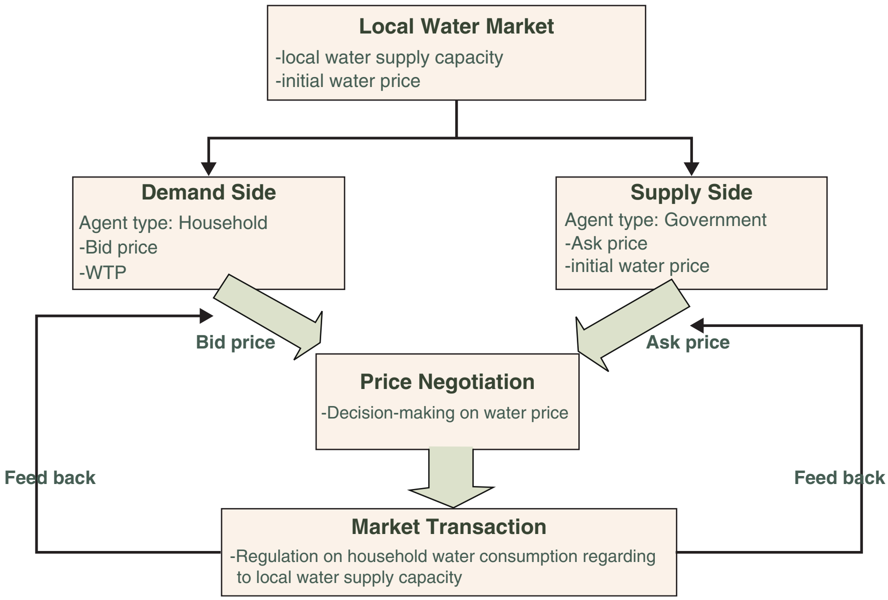


Fig. 6.1 Conceptual scheme of the water market

Demand Side of the Water Market

Budget Constraints for Household Water Consumption

Each household is assumed to know what percentage of income can be used for water consumption each month. The 5% rule reported by the World Bank assumes an elastic demand for water when the cost is less than 5% of household income and an inelastic demand when the cost exceeds 5% of household income (World Bank 1992). We hereby use 5% of household income as a maximum budget constraint for household water consumption.

In this chapter, we divide households into three groups according to income: poor households, middle-income households, and rich households. We assume that different groups have different budget constraints, and that the maximum household water consumption in each group will not exceed 5% of household income. Therefore, we obtain the budget constraints for household water consumption for poor households, middle-income households, and rich households, Y_p, Y_m, and Y_r, respectively, as follows:

$$\begin{aligned} \mathrm{Y} &= \left\{\mathrm{Y}_{\mathrm{x}} \middle| Y_p, Y_m, Y_r\right\}, (x = p.m, r) \\ Y_p &= 5\% * income_{poor} \\ Y_m &= 3\% * income_{middle} \\ Y_r &= 1\% * income_{rich} \end{aligned} \quad . \tag{6.1}$$

Evaluating Household Satisfaction with Water Consumption

We assume that the difference in water consumption produces different satisfaction levels for households and that there is a positive correlation between water consumption and satisfaction. As a result of the cost of water, the household water consumption will not exceed a volume whereby the total charge for water consumption approaches the *WTP* but is less than budget constraint *Y*. We consider the satisfaction produced by this volume of water consumption to be threshold *K*. Finally, the growth rate of household satisfaction *S* with water consumption *V* is given by the following logistic functional form:

$$dS/dV = rS(1 - S/K). \tag{6.2}$$

Based on this equation, we transform the integral into function *S* in terms of *V*, as follows:

$$\begin{aligned} S(V) = K/(1 + Ae^{(-rV)}) \\ where, A = K/S(0) - 1 \end{aligned}, \tag{6.3}$$

where $A = K/S(0) - 1$ and *K* and *A* are constants.

Household WTP for Water

As shown in (6.3), household satisfaction is achieved if water consumption does not exceed 5% of household income. Here, we consider the *WTP* to be the total cash that households would like to pay for water. Therefore, we assume the *WTP* to be a function of individual income and the satisfaction with a certain volume of water consumption. In addition, the total cost of water consumption will be less than the budget constraint *Y*. We describe the dependencies of these variables as follows:

$$\text{WTP} = \frac{Y * S^2}{b^2 + S^2}, \text{ (b is a constant)}, \tag{6.4}$$

where *b* is a constant. This equation has the same form as that used to model land prices (Filatova et al. 2008).

In (6.4), *Y* and *S* are calculated according to (6.1) and (6.3), respectively. Based on the idea proposed by Filatova et al. (2008), the individual *WTP* increases as satisfaction with water consumption increases but never exceed one's budget *Y*. Thus, according to (6.4), *WTP* increases monotonically to Y when $S \rightarrow \infty$. The value of b controls the slope of the function, which can be considered as a proxy for households' affordability of all other goods in their daily life, reflecting their relative influences on the *WTP* for water consumption. As $b \rightarrow \infty$, (6.4) becomes flatter and at the point where $S = b$, $WTP = Y/2$.

Unlike in Filatova's work, we assume that the household WTP will be influenced by the following three considerations:

- Individual *WTP*, which is determined by (6.1–6.4), reflects the *WTP* of each household without considering other factors.
- Neighborhood influences reflect the influence of neighbors on household WTP. The basic principle is that for each household, if more than 50% of the neighbors have a higher *WTP* than that household, then the *WTP* of that household will increase; otherwise, the *WTP* of that household will decrease. In the HWCSim model, the Moore 4 neighborhood is used.
- Global influences reflect the average *WTP* of all households in a society on the WTP of a single household.

Accordingly, the final *WTP* of each household is defined as the average value of the household WTP, the neighborhood *WTP*, and the global *WTP*.

Final Bid Price of Households

As in the study by Parker and coworkers (Filatova et al. 2008), we differentiate between the *WTP* and the final Bid Price of households, and between the *WTA* and the Ask Price of the government during the price negotiation process. The purpose of this simulation is to determine the *WTA* of the government such that price the total household water consumption will not exceed the local water supply capacity (the threshold for total amount control).

As in daily life, when buyer and seller try to reach a consensus on the price of a product, both the buyer and seller attempt to maximize their gains from the trade. Therefore, the Bid Price of the buyer tends to be less than the individual *WTP*, and the Ask Price of the buyer tends to be more than the *WTA*. As one of the necessities of daily life, there is no substitute for water. As such, households must pay for water consumption. However, if the government negotiates with households in determining the new water price, it is assumed that the Bid Price of households will be below their WTPs, as follows:

$$P_{\text{bid}} = WTP * (1 - \varepsilon), \text{Where we seem}\, \varepsilon \text{ as a constant,} \tag{6.5}$$

where ε is a constant.

Supply Side of the Water Market

WTA of the Government

Water is a natural resource because of its limited supply. As such, water is a public good in Japan. However, unlike with other public goods, such as land, the government acts as the supplier and regulator of local water market according to local water supply capacity. Accordingly, we herein consider the local government to be the single supplier of water.

We assume that the local government tries to control the total amount of household water consumption so as not to exceed the threshold of the local water supply capacity. This is accomplished by the regulation of water price. In order to set the new water price, the government has to negotiate with households and make sure that at least 50% of households can easily afford their water. As a computer experiment, the government agent will set the water price for negotiation with households in order to realize its policy on the regulation of total amount control of water consumption. In the HWCSim model, the water price set for the computer experiment is defined as the *WTA* of government.

Ask Price of the Government

In a market, the Ask Price of the seller is expected to be different than the *WTA* of the seller. In the present research, it is assumed that a water price exists, which the government decides based on the water supply capacity in the initial step. Thus, the Ask Price of the government differs in each simulation loop to reach a balance between water consumption and water supply capacity, as follows:

$$P_{t,ask} = P_{t-1}(1 + a), (0 < a < 1). \tag{6.6}$$

In (6.6), the Ask Price is denoted as $P_{t,ask}$, which is different in each simulation loop. At the beginning of the simulation, there will be an initial water price, and the government will calculate the total amount of household water consumption based on this price, if the total amount of household water consumption is larger than the threshold of the total amount control, the government will update the Ask Price using (6.6). In this equation, a is a constant that represents the government's attempt to regulate household water consumption through increasing or decreasing the water price, and a is the markup or markdown according to the water price at Step $t-1$.

Total Amount Control of Household Water Consumption

Government Total Amount Control

In the HWCSim model, the government agent will perform total amount control of household water consumption. In the first step of simulation, the initial water price is set by the government agent, and the distribution of household water consumption is assumed to be a normal distribution. Thus, the average volume of household water consumption is prepared to reflect the water consumption. The household agents determine their own consumption volume according to their attributes, i.e., the number of family members and the average volume of household water consumption within different income groups. Then, the government will calculate the total volume of household water consumption and decide whether to request a new price to regulate household water consumption activity. If the government agent decides to request a new water price, which is defined herein as the Ask Price, the simulation will enter the price negotiation stage. After the negotiation process, a new water price will be published by the government agent, and the households will adjust their water consumption according to this new price and their income at the next simulation loop. The details of this simulation flow are shown in Fig. 6.2.

Negotiation Process for Water Price

We consider the negotiation of water price between the government and households to be a bilateral trade negotiation process, in which the household side puts forward a Bid Price based on the individual *WTP* and the government side puts forward an Ask Price based on the initial water price, and the two sides negotiate the final water price as a market transaction.

The water market proposed herein is differs from traditional public goods markets in that there is a single supplier and numerous buyers. Therefore, the price negotiation between the government and each household cannot be carried out. As such, the price negotiation will take place between the government and a number of households through a policy attitude investigation. When the

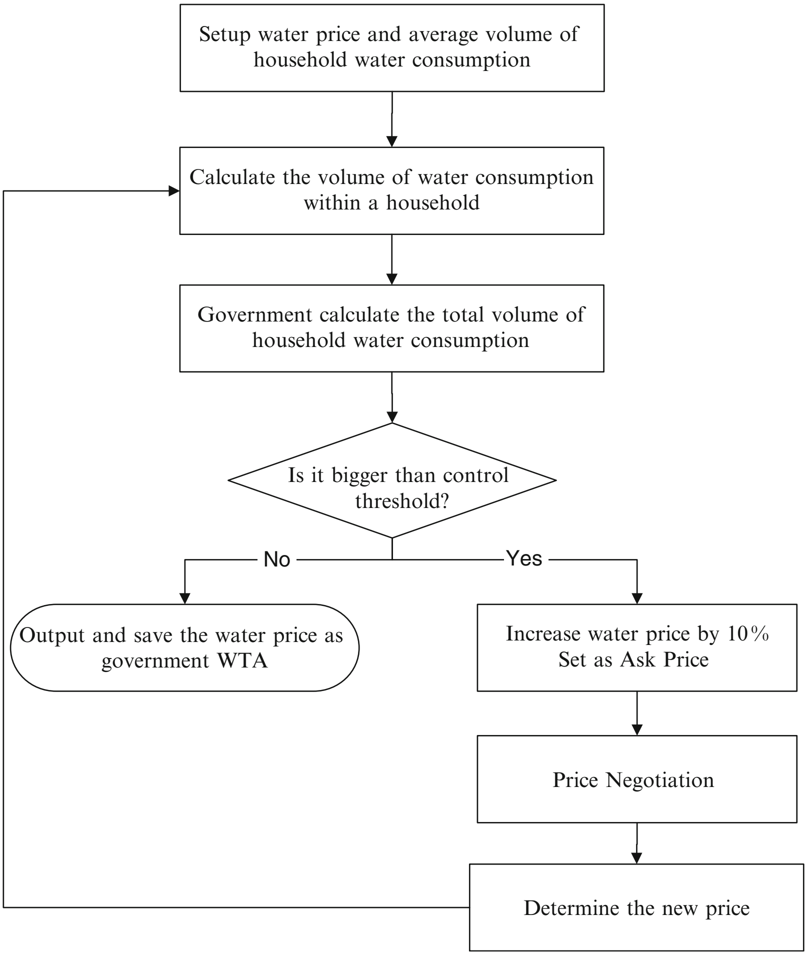


Fig. 6.2 Decision tree for the government to control the total amount of household water consumption

government requests a new water price, we assume that the government will hold public hearings to estimate the feasibility of the new price. During the public hearing, local households from different income groups will be asked to participant in the policy attitude investigation, which is carried out through the distribution of a questionnaire on household policy attitude regarding the new water price. Households fill out the questionnaire according to their WTP and expectation price, which is defined herein as the Bid Price.

The policy attitudes reported by households are defined as individual policy attitudes, which are divided into primarily two ranges representing positive and negative feedback, respectively. Table 6.1 shows the decision table for determining the individual policy attitude.

Table 6.1 Household policy attitude toward government Ask Price

	Poor households			Middle-income Households			Rich households		
Bid Price ≥ Ask Price	Y	N		Y	N		Y	N	
WTP ≥ Ask Price	/	Y	N	/	Y	N	/	Y	N
Policy attitude range	[0,1]		[−1,0)	[0,1]		[−1,0)	[0,1]		[−1,0)

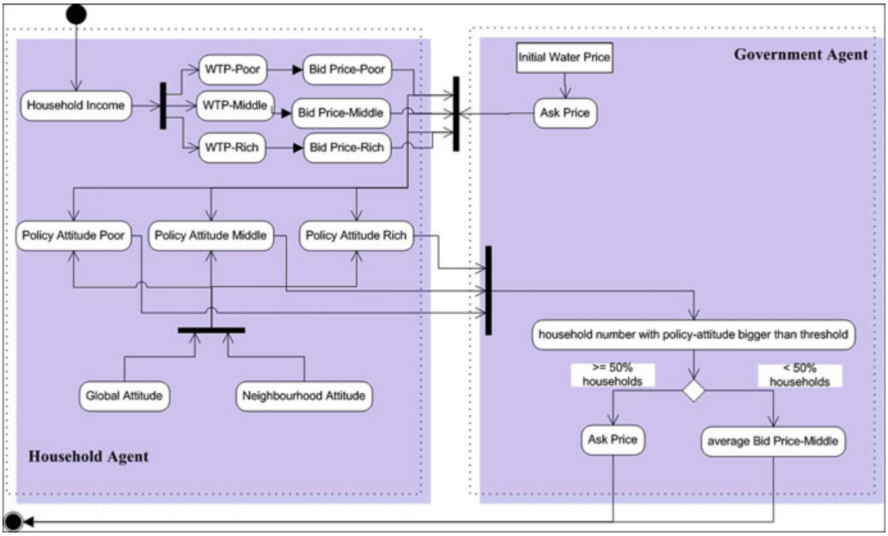


Fig. 6.3 UML state diagram of the negotiation process

The state transition in the process of water price negotiation is shown in detail in Fig. 6.3.

In the HWCSim model, the government estimates household policy attitude based on the following three considerations:

- Individual policy attitude is directly determined by households by comparing their Bid Price with the Ask Price of the government.
- Neighborhood influences reflect the influence of neighbors on household policy attitude. The Moore 4 neighborhood is used in the HWCSim model, and the average policy attitude of neighbors is defined as the neighborhood policy attitude.
- Global influences reflect the influence of society on household policy attitude. One example of such an influence is propaganda on the reduction of water consumption. The average policy attitude of all households is defined as the global policy attitude.

The final household policy attitude is the average of the individual policy attitude, the neighborhood policy attitude, and the global policy attitude. In the

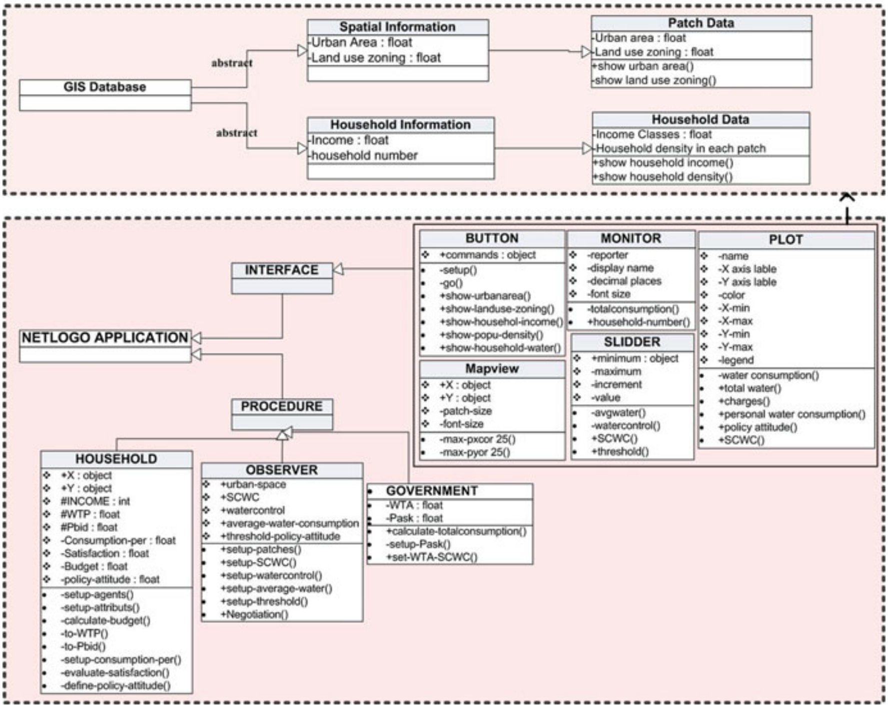


Fig. 6.4 UML class diagram of the HWCSim model

HWCSim model, if the final value of the policy attitude is larger than the threshold, which means that households agree to the Ask Price, then a threshold is used for household policy attitude evaluation.

Finally, the government will decide the Ask Price. As shown in Fig. 6.4, the basic principle is that if the threshold policy attitude is exceeded by at least 50% of households, then all of the households must accept the Ask Price. This price will be set as the new water price in the next simulation loop; otherwise, the Ask Price will be set as the average Bid Price by middle-income households.

In the following session, we discuss how to conduct the simulation using the HWCSim model.

Development and Implementation of the HWCSim Model

System Development

The HWCSim model is developed using the Netlogo platform. As shown in Fig. 6.4, there are basically two components in the Netlogo application, namely, the interface component and the procedure component. The objects in the interface component perform actions through the procedure component. Among the six objects in the interface component, the button object is used to set up spatial information on patches and to start or stop simulation. The Mapview object can be used to reflect the spatial information and present simulation results, for example, the urban space, the population density, and the household characteristic can be visualized by the Mapview object. In addition, simulation results of the average values of agents' attributes or global parameters can be presented by the plot objects. In this research, we use plot objects to show the time-trend changes in the simulation process, such as the total amount of household water consumption, the average total charges for household water consumption for different income groups, the household policy attitude, and the water price. The slider objects allow the user to adjust or present global parameters, such as water price, e.g., average household water consumption (averwater) and threshold of the local water supply. The switch object allows the user to set options with or without the total amount control in the simulation process. Another important component for the HWCSim model, as shown in Fig. 6.4, is the procedure component, which allows the user to develop the simulation model.

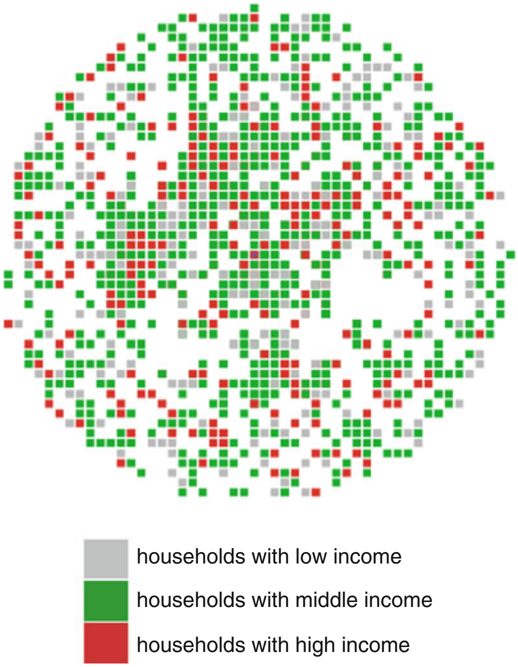
Hypothetical Urban Space Accommodating Household Attributes

In this simulation, the Japanese city of Kanazawa was chosen as a case study area. In order to accommodate household attributes, we prepared a hypothetical urban area and household attributes for the simulation. The spatial dataset is created based on the real dataset for Kanazawa City, including urban planning information, household attributes, and their spatial distribution for this simulation (Fig. 6.5). We assumed that the households are stable in number and location. In order to reduce the computation time, we created 1,500 household agents in the virtual urban space to represent the 450,000 households in Kanazawa City. Therefore, one household in the virtual space corresponds to 300 households in the real society, and the households are divided into the three income groups.

Parameters Setting and Model Behavior

The system interface of the HWCSim model is shown in Fig. 6.6, which is developed using Netlogo. We assumed that households are stable in number and location. In order to validate the model, we analyzed the simulation results based on the parameters in the model.

Fig. 6.5 Spatial distribution of households



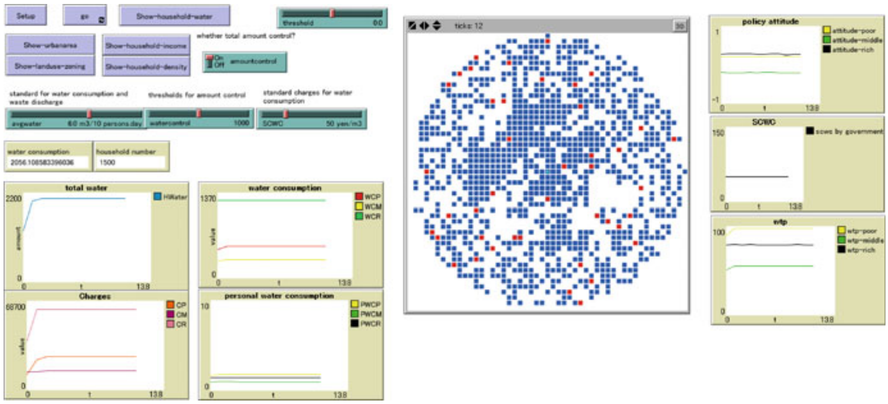


Fig. 6.6 Model interface of the Netlogo platform

Threshold of Household Satisfaction with Water Consumption

As described in Sect. "Evaluating Household Satisfaction with Water Consumption", we argued that household satisfaction with water consumption would follow a logistic functional form. Basically, households will not leave water running for the entire day in order to increase satisfaction with water consumption if the desired amount of water has already been consumed. Moreover, although the WTP or household satisfaction for water consumption is limited, there is a basic requirement for daily water consumption. These two considerations yield two thresholds for household satisfaction. As proven previously, consumer satisfaction with a product/service commonly has thresholds at both lower and upper levels (Hom 2000).

Generally speaking, people require at least 0.2 m^3 of water for daily life, the satisfaction with the minimum demand for water consumption is considered to be the lower threshold. Thus, the upper threshold of household satisfaction must be defined. We assume that the household satisfaction gained by water consumption will obey the law of diminishing marginal utility. We therefore consider the relationship between the volume of household water consumption and the corresponding household satisfaction based on (6.3) in which the constants are assumed to be $k = 9$, $A = 9$, and $r = 5$.

Based on (6.3), we calculated household satisfaction according to water consumption from 0.2 m^3 to 10 m^3 of water per day. The increase in household satisfaction with increasing water consumption in increments of 0.1 m^3 has also been calculated and is shown in Fig. 6.7.

As shown in this figure, the value of dS/dV (increase in household satisfaction with the increase in water consumption) is initially rising. However, dS/dV begins to decrease when $V = 0.4$, and the household satisfaction S continues to increase until $V = 1.6$. We consider a household water consumption of less than 1.6 (m^3/day)/person to be the range of increasing household satisfaction with respect to water consumption. We assume that households in different income groups will seek satisfaction in this range. As such, we choose the satisfaction produced by consuming 0.6 m^3, 1.0 m^3, and 1.7 m^3 of water as the upper levels of household satisfaction of poor, middle-income, and rich households, respectively. Thus, satisfaction values of 6.2, 8.4, and 8.9 are defined as the upper levels of household satisfaction in the following simulation.

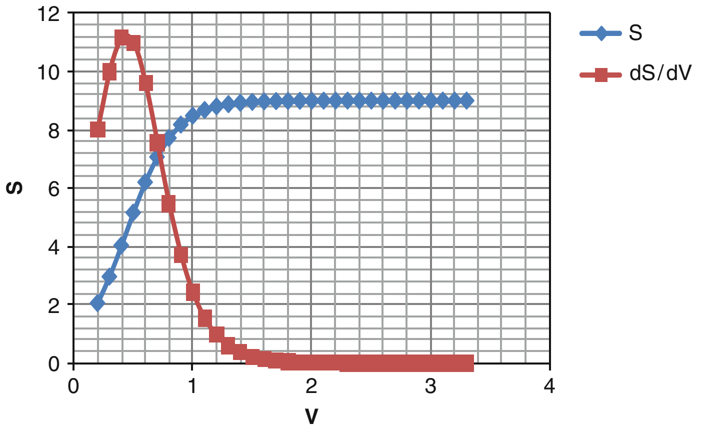


Fig. 6.7 Household satisfaction per 0.1 m^3 of water consumption ($K = 9$, $A = 9$, $r = 5$)

Threshold of Total Water Consumption and Other Parameters Regarding Household Water Consumption

The required initial values for parameters, including "avgwater", which represents the average household water consumption, "threshold for amount control", which is the local water supply capacity, and "SCWC", which represents the standard charges for water consumption, are shown in Fig. 6.8.

We started the simulation with the initial parameter settings. As shown in Fig. 6.9, the total amount of household water consumption, i.e., "total water", increased sharply at the beginning of the simulation because households initially require high satisfaction with water consumption. However, the total amount of water consumption decreased because of the water price negotiation process and

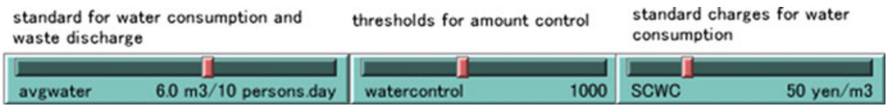


Fig. 6.8 Initial parameter values

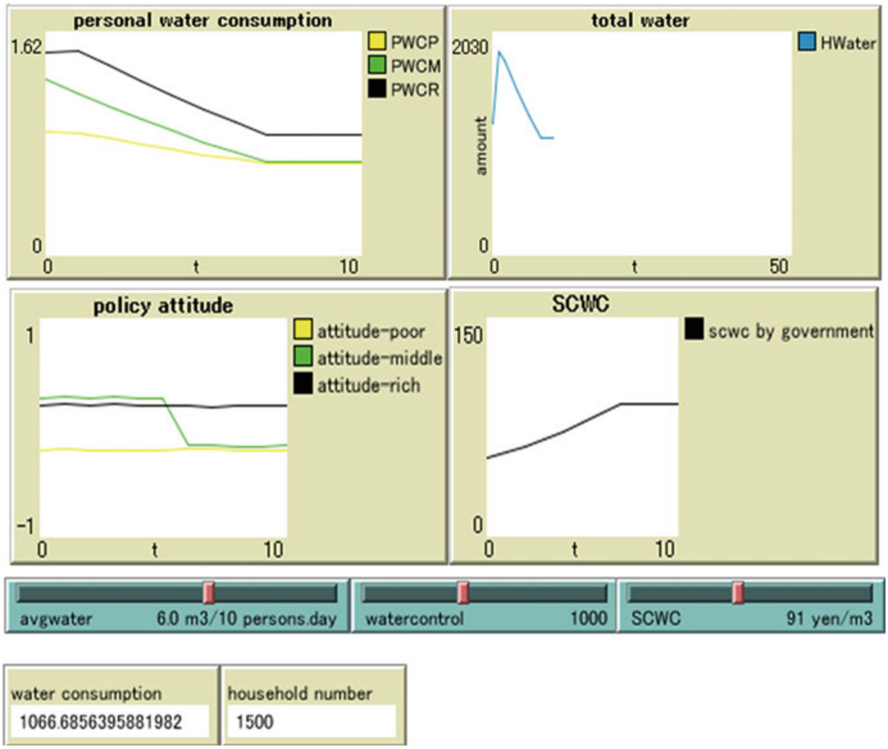


Fig. 6.9 Simulation results using the initial parameter settings

government regulations implemented in the model. Finally, the total water consumption became stable at a value below the threshold.

In order to facilitate observation of the model behaviors in the following analysis, in the following, we start the simulation without total amount control and then turn on “amountcontrol” (button shown in Fig. 6.6).

The realization of the above-described process resulted in an increase in water price, as shown by the plot of *SCWC* in Fig. 6.9, and *SCWC* grew from 50 to 91. As the water price increases, the household policy attitudes of middle-income households fluctuate significantly, which means that these households initially agree with the increased water price, but as the price approaches the *WTP*, the positive policy attitude of each household changes. Although the policy attitudes of rich and poor households are much more stable, the difference between these two types of household is that the former is always positive whereas the latter is always negative. These results appear to be reasonable because rich households have a large *WTP*, whereas poor households have a smaller *WTP*. In the following, we describe how the simulation results change with changes in the parameters.

- Model behavior: total amount control of water consumption, “watercontrol”

We continued to run the simulation and adjusted the value of “watercontrol” from 1000 to 800. As shown in Fig. 6.10, the standard charge of water consumption

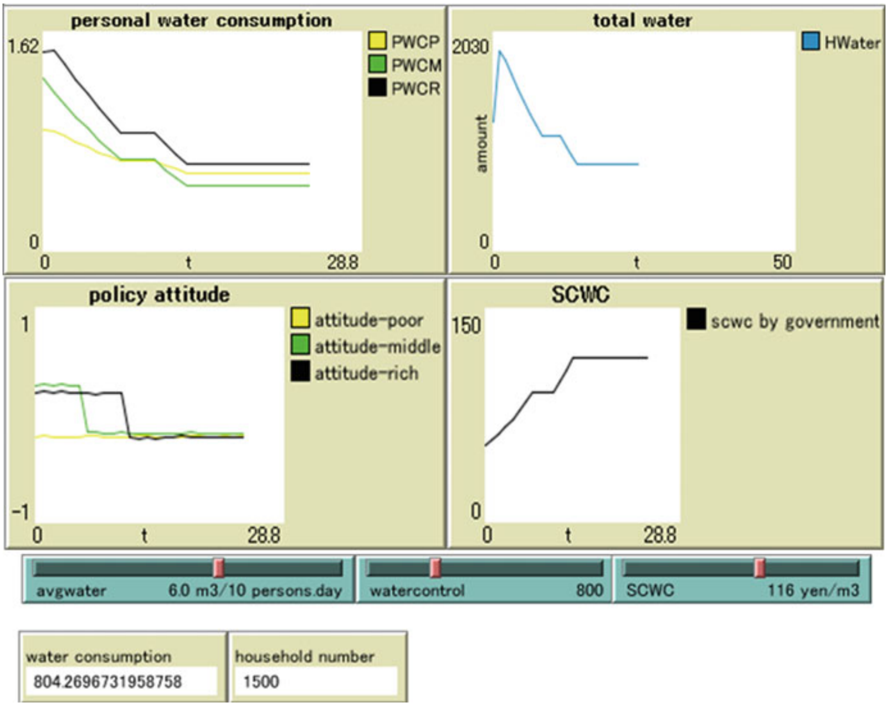


Fig. 6.10 Simulation results for the case in which “watercontrol” decreased to 800

(SCWC) increased because of the decrease in the threshold of total amount control. The policy attitude of rich households also decreased to a negative value, which means that some rich households began to disagree with the increasing water price. Thus, after the negotiation process, the new water price tends to become stable at 116 yen/m^3, where the total water volume is 804 m^3. Although this value it is not strictly below the threshold, it is also reasonable considering the randomness of personal activity.

Accordingly, when the price charged for water is 116 yen/m^3, the total amount of household water consumption will be very near the control threshold of 800 m^3. This price is considered to be the government *WTA* that should be achieved through the process of simulation.

After the simulation introduced in the last paragraph, we continued to run the simulation and increased the value of “watercontrol” to 1,200. As shown in Fig. 6.11, the values of total water and personal water consumption increased. At the end of simulation, the value of total water fluctuated to 1200 m^3 and became relatively stable at 1216.8 m^3. These results are related to the decrease in the price of water, i.e., the *SCWC*, in the present research. As indicated by the plot of *SCWC*, *SCWC* decrease greatly from 116 yen/m^3 (simulated previously) to 88 yen/m^3. Correspondingly, the policy attitude of households becomes more positive,

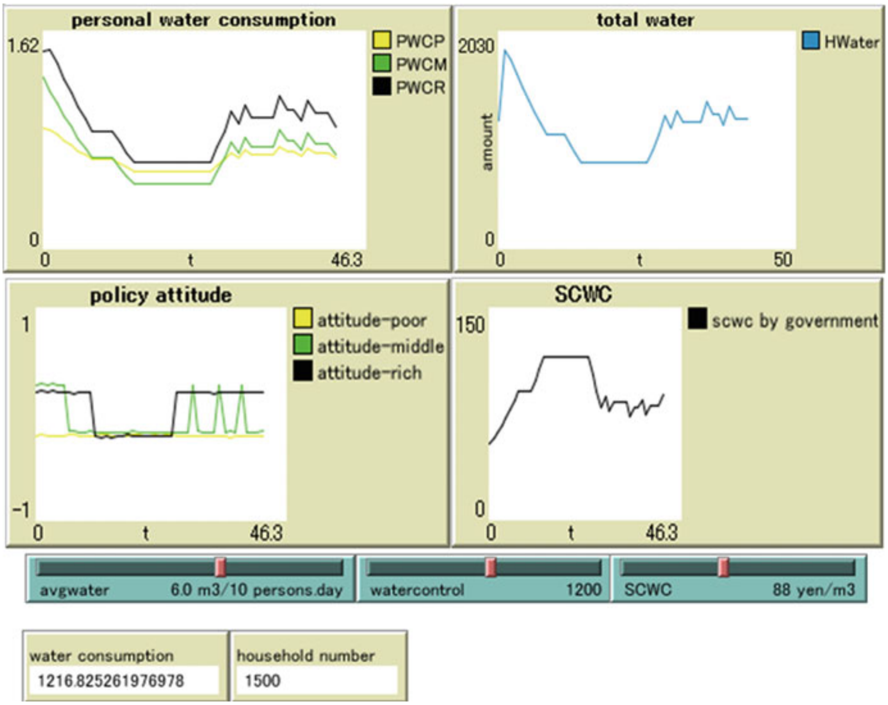


Fig. 6.11 Simulation results for the case in which “watercontrol” increased to 1,200

especially with respect to rich households. Moreover, the policy attitude of middle-income households changed in a waveform.

- Model behavior: "avgwater"

Here, we restart the simulation using the initial parameter settings in order to test the behavior of the model by adjusting the value of "avgwater", i.e., the average volume of household water consumption. Here, "avgwater" will be used to configure the different average water consumption volumes for the different income groups of households. As shown in Fig. 6.12, the simulation results are basically stable when "amountcontrol" is off. Then, "amountcontrol" was turned on as the simulation was running. As mentioned above, the function of government total amount control began to operate so that the total amount of water consumption increases and the decreases so as to obey the model function.

When "avgwater" is set to be 3.0 lower than the initial value, the total household water consumption was below the threshold, which was set to be 1,000. Then, *SCWC* decreased slightly when "amountcontrol" was first turned on, but the subsequent sharp increase in household water consumption associated with the upper level of satisfaction causes SCWC to increase. As shown in Fig. 6.12, after

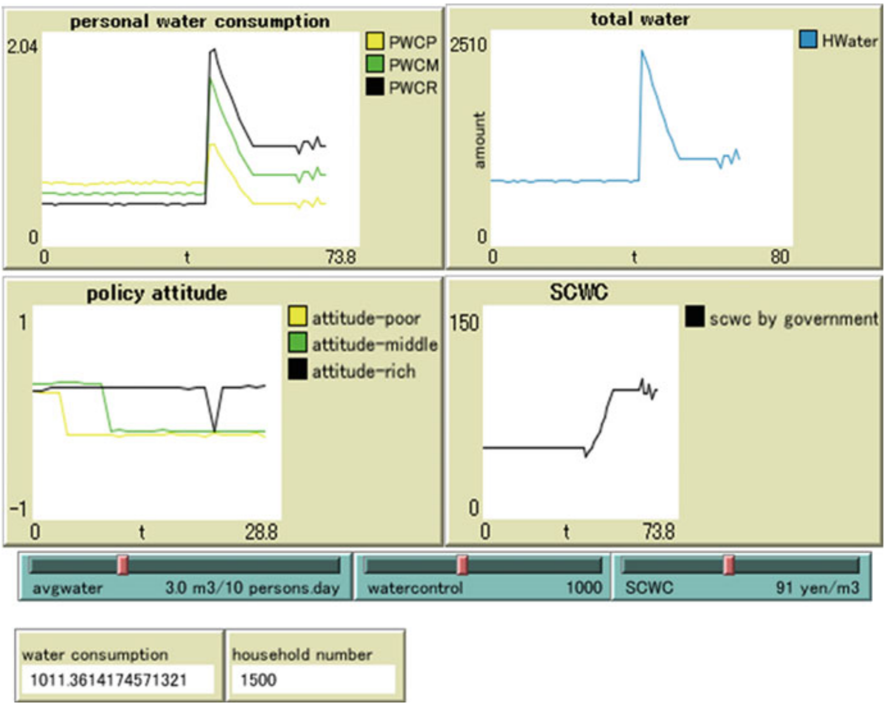


Fig. 6.12 Simulation results for the case in which "avgwater" decreases to 3

decreasing slightly, *SCWC* increased and became relatively stable at 91, where the total water consumption was 1011.36 m^3, which is near the “watercontrol” threshold. During this process, different households had negative policy attitudes with regard to the increase in *SCWC*. Among these households, the policy attitudes of only the rich households return to being positive after decreasing slightly.

The simulation is restarted after adjusting “avgwater” to 9 m^3/10 persons·day. The simulation results are shown in Fig. 6.13, in which the plot of *SCWC* increased noticeably because of the increase in “avgwater”, i.e., average water consumption. As a result of the increase in water price, households must decrease their water consumption. Thus, as shown in Fig. 6.13, the total water consumption and the personal water consumption decreased sharply. In contrast, the volume of personal water consumption of rich households did not change noticeably during the simulation process even though the water price became higher. This phenomenon can be attributed to the large *WTPs* of rich households, which indicate relatively low sensitivity of water consumption activities to the fluctuation of water price. In contrast to rich households, poor households have a greater sensitivity to changes in water price. These findings are established by the simulation and are supported anecdotally, thus proving the effectiveness and reasonableness of the HWCSim model.

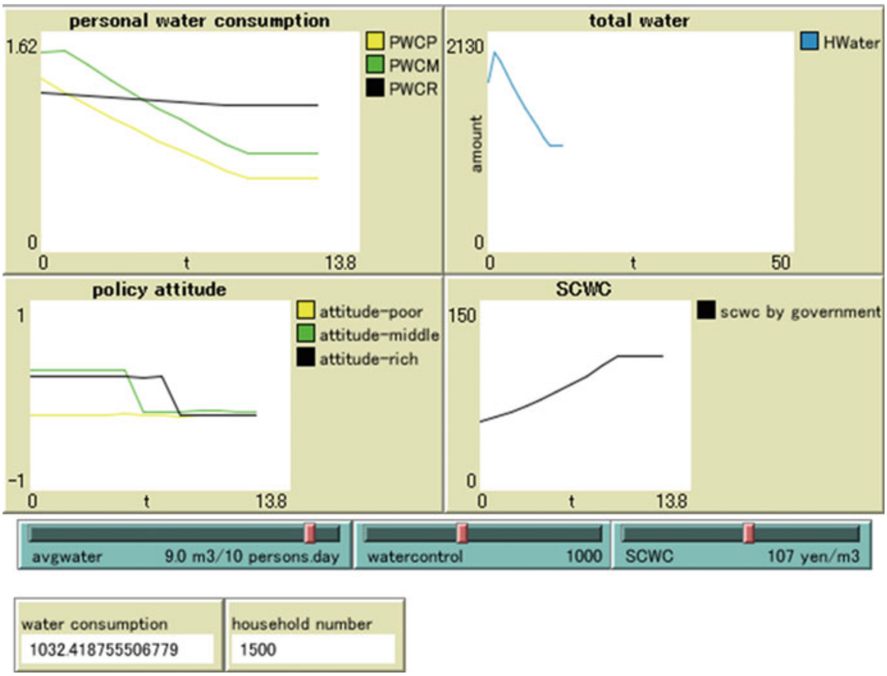


Fig. 6.13 Simulation results for the case in which “avgwater” increased to 9

Model Validation Using Real Data for Kanazawa

Validation of the HWCSim model is conducted using the real dataset of Kanazawa City, Japan. We intend to use the real data for household water consumption for Kanazawa City as the threshold of "water control" in the model in order to simulate the average volume of household water consumption and the charge in the *SCWC*. Then, the simulated results and the real data will be compared in order to validate the HWCSim model.

Based on the census survey of Kanazawa in 2009, there are 454,607 households in Kanazawa City, and the total water consumption that year was 39,295,827 m^3. Thus, each household consumed approximately 0.24 m^3 of water per day, and the total water consumption for 1,500 households was 355 m^3/day in the virtual urban area. Based on the *SCWC* published by the Kanazawa Water and Energy Center, assuming that the household water consumption was 10–20 m^3/month, the actual *SCWC* is obtained as 113 yen/m^3. The HWCSim model is validated using the parameter settings shown in Fig. 6.8, with the exception of the water control value. According to the basic principle of model validation, as described above, we set the water control to be 355 m^3. The simulation results are shown in Fig. 6.14.

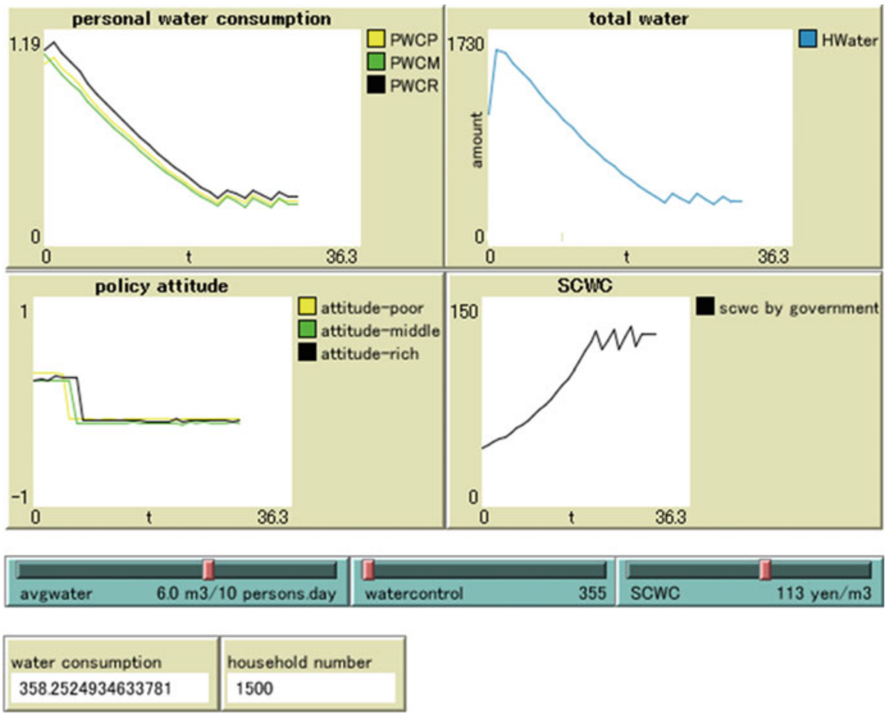


Fig. 6.14 Simulation results obtained using real data for Kanazawa City

In Fig. 6.14, the model behaves in a manner similar to that described in Sect. "Parameters Setting and Model Behavior". The household water consumption decreased because of the increasing *SCWC*. As shown by the personal water consumption chart, the difference in average household personal water consumption according to income group decreases accordingly. Since *SCWC* is relatively lower and is acceptable to different households, we find that despite small fluctuations, initially, the policy attitudes of households were relatively stable and were all positive. Furthermore, these values are relatively high. Since *SCWC* exceeded 90, the policy attitudes of households exhibited significant decreases, until eventually fluctuating very slightly around zero. The final results for the average volume of household water consumption, referred to as personal water consumption, for different households has been reduced to the range of from 0.22 to 0.27 m^3/household·day. This result is very similar to the real data for Kanazawa City. In contrast, the simulation results for *SCWC* indicate that the actual *SCWC* is just 113 yen/m^3.

Conclusion

In this chapter, the HWCSim model is designed to reflect the process of total amount control of household water consumption. This model can simulate the process of water price formation through a water price negotiation process between households and government, where the household policy attitude impacted by the water price requested by local government under the constraint of the local water supply capacity is considered through total amount control. Finally, as validated by the real data for Kanazawa City, the HWCSim model is found to be applicable for simulating the process of household water consumption regulated by government total amount control in planning practice. The simulation results, including water price and household water consumption, are very similar to the actual data obtained for Kanazawa City.

In the HWCSim model, we propose the household *WTP* for water consumption through evaluating the satisfaction with household water consumption. We also introduced the interaction between government agents and household agents in deciding water price, which is herein referred to as negotiation. As a result, the HWCSim model can reflect the mechanism of total amount control of the local government, while considering local water supply capacity, water price, household policy attitude, and their attributes. In the HWCSim model, households can reduce or increase their water consumptions according to their *WTP* and the water price requested by the government. The policy attitudes of these households will eventually impact government decision-making regarding water price.

The present research has limitations. For example, we use random factors having ranges to reflect differences in water consumption and policy attitudes among households of different income brackets, and the probability distributions of these random factors have not been taken into account. These limitations should be rectified in the future.

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