Stoch Environ Res Risk Assess (2013) 27:629–641
DOI 10.1007/s00477-012-0628-3

ORIGINAL PAPER

A scenario-based water conservation planning support system (SB-WCPSS)

Xinhao Wang · Amy Burgess · Jeff Yang

Published online: 19 August 2012

Abstract In this study a water consumption model is built into a scenario-based planning support system (SB-WCPSS). The SB-WCPSS consists of four components—(1) a model input graphic user interface, (2) a community spatial database, (3) a set of drinking water consumption models, and (4) output display. The SB-WCPSS is implemented with a commercial planning support system software package—CommunityViz. The model is applied using data in Cincinnati, Ohio, USA to demonstrate the scenario development. In the application, water consumption consists of land use based indoor, turf, and pool water usages. Climate change is reflected in monthly temperature and precipitation. By specifying anticipated future land uses and associated water consumption rates, temperature, and precipitation, SB-WCPSS users can analyze and compare water consumptions under various scenarios, using maps, graphs, and tables. Parcel-based daily water consumptions were computed and summarized spatially by neighborhood, block group, or land use type. The results demonstrate that water conservation strategies, such as xeriscape, can reduce turf water usage. Indoor water consumption depends on the number of people who use water and how they use water. The study shows that the SB-WCPSS structure is sound and user friendly. Future improvement will be on enhancing various components, such as using parcel-based data and more robust water consumption models. The system may be used by water resource managers and decision makers to adapt water resources (e.g., watersheds and infrastructure) to climate change and demographic and economic development.

Keywords Climate change · Planning support system · Water consumption · Infrastructure adaptation

X. Wang (✉) · A. Burgess
School of Planning, University of Cincinnati, Cincinnati, OH 45221-0016, USA
e-mail: Xinhao.wang@uc.edu

J. Yang
U.S. Environmental Protection Agency,
Office of Research and Development,
National Risk Management Research Laboratory,
26 West Martin Luther King Drive, Cincinnati, OH 45268, USA

1 Introduction

While water resources in some areas are plentiful allowing over consumption to go un-noticed other locations are not as fortunate. Further, the availability of water resources in some regions of the world is erratic due to climate change. A study in 2007 found that water consumption is positively related to climate change. The study discovered that for every 1 °C temperature increase in mean annual temperature there is a 60.76 L increase in the amount of water per dwelling (Balling and Gober 2007). Therefore, as the temperature in cities increases, so does water consumption. An increase in precipitation has the opposite effect on water consumption. Balling and Gober (2007) also found a reduction (increase) in annual precipitation of 10 mm would increase (decrease) water use by 4 L per capita per day according to data taken in Phoenix, Arizona.

Finding ways to conserve water is a concern for those less fortunate areas. Water consumption in the United States is seven times greater than the amount necessary for survival (Kenny et al. 2009). Research and practices in water resource conservation have already begun. One of effective route for conserving water is to focus on residential water conservation. The USEPA Water Resource Adaptation Program (WRAP) aims to provide water resource managers and decision makers with the tools they need to adapt water resources to future climate change,

change in demographics, and economic development (United States Environmental Protection Agency 2009). One aspect of the WRAP research is to understand the demand for water and energy under various urban development scenarios. Scientists have developed forecasting and assessment tools to forecast long-term variations or trends in precipitation and stream flows (United States Environmental Protection Agency 2009). They also have started to compile ways in which decision makers can plan for changes in water availability in arid regions and have documented engineering marvels that work to conserve water.

This paper presents another way to support three of the five EPA WRAP goals: clean air and global climate change, clean and safe water, and compliance and environmental stewardship (United States Environmental Protection Agency 2009). A scenario-based water conservation planning support system (SB-WCPSS) is developed to establish the connections between domestic water consumption and planning alternatives in the context of climate change. The objective of the SB-WCPSS is to enable planners to relay water conservation methods into the plan making process in ways that are easily understood. After a user adjust water consumption rates, land use configuration, and/or climate change (precipitation or temperature) in a study area SB-WCPSS displays water consumption for each scenario using maps, graphs, and tables. The differences between scenarios also can be compared.

With the help of scenarios-based planning approaches planners can involve the public in the collaborative environmental planning and decision-making process in order to help communities better understand the challenges and opportunities and make informed decisions (Randolph 2004; Klosterman 2007; Guo and Huang 2009; Wang et al. 2010). Previous studies have shown that scenario-based planning has been used to facilitate group interactions and to achieve agreed-upon goals and deal with common concerns about public policy issues such as education, land use, leadership, transportation, and environment (Klosterman 2001; Cummings 2007; Li et al. 2009, 2011). Using a scenario-based planning support system to involve the public more readily in community planning related to water consumption will bypass the problems associated with identifying issues only after major impacts have been caused (Fletcher and Deletic 2008). It is important to show water users that some water uses are not as necessary as others. Therefore, planners and decision makers need to educate the public of options and institute policy changes that will reflect and encourage conservation (Schreck and Farber 2009). Planning support systems can be used to evaluate alternative futures in ways that may not have been possible before their existence (Geertman and Stillwell 2003; Deviney et al. 2012).

Another component of the SB-WCPSS is developing scenarios. Scenarios are a mechanism employed by planners to develop alternative plans for assisting decision making. They are important in the planning process because of the future aspect that they maintain. Scenarios can be used to “discover unknown or poorly understood interrelationships” and also to “engage broader public input into the planning process” (Hopkins and Zapata 2007). The scenario-based planning process works by creating a set of plausible alternatives and uses them to illustrate likely outcomes of various decisions (Li et al. 2010). Scenarios need to reflect a development story, explaining how life could feasibly be lived and demanding that each possible scenario be analyzed objectively (Avin and Dembner 2001; Liu and Tong 2011; Zhao et al. 2012). Questions can be answered such as “What do you think might happen if all residents of a city reduced their indoor water consumptions by installing low flow toilets and other technologies in their household?” The SB-WCPSS is implemented with a commercial planning support system software package—CommunityViz (Placeways, Boulder, CO). CommunityViz can be used to make quicker, increasingly informed decisions about planning of various issues and can also be used to engage and inform the public (The Orton Family Foundation 2004). The software can help to make choices about “where and how to build, or how to use land and resources” (The Orton Family Foundation 2004). This analysis engine helps to reveal possibilities and opportunities visually (Sipes 2003). The components used in scenario constructor include data, assumptions, dynamic attributes, indicators, charts, alerts, and reports.

The research presented in this article uses the following progression. Section 2 covers the methodology and data used in the building of the SB-WCPSS. Section 3 describes the SB-WCPSS specifically including, inputs and outputs and how to use the model. Section 4 explains the development of the scenarios used in the model. Section 5 explains the results of the different scenarios. Section 6 summarizes contributions of the model to the planning field, addresses limitations, and provides recommendations for further research.

2 Materials and methods

2.1 Data

Data required for the SB-WCPSS include;

- Monthly average maximum daily temperature for Cincinnati from 2004 to 2009 (National Weather Service 2010).
- Monthly precipitation for Cincinnati from 2004 to 2009 (National Weather Service 2010).

- Monthly aggregate water consumption for the Cincinnati region from 2004 to 2009 (Greater Cincinnati Water Works 2010).
- Property parcel polygons with land use classification (Cincinnati Area Geographic Information Systems).
- 2000 Census block group polygons with population and number of households (Cincinnati Area Geographic Information Systems).
- Zip code polygons (Cincinnati Area Geographic Information Systems).
- Building polygons (Cincinnati Area Geographic Information Systems).
- Pavement polygons and lines (Cincinnati Area Geographic Information Systems).
- Aerial photo (Cincinnati Area Geographic Information Systems).
- Turf polygons and outdoor swimming pool polygons were digitized from aerial photos in reference to building and pavement data.

2.2 SB-WCPSS

The SB-WCPSS is made up of four components: user input, database, simulation models, and output. The input of the system consists of three parts. The first part is the change of lifestyle, which represents how people use or misuse water resources in light of climate change. In terms of water consumption, it may be reflected in modifying landscaping to reduce the amount of turf, using water conservation showering heads, etc. The second input consists of future land use and/or infrastructure plans which are represented by spatial data layers such as a land use plan map or water distribution network. A user may modify data layers to analyze the impact of different development plans. The third part of input is climate change, which is reflected by changes in mean monthly temperature and precipitation. The SB-WCPSS database contains both spatial and non-spatial data, which represent user input, city characteristics, and modeling output. The simulation model component consists of various simulations or optimization models which compute corresponding changes from adjustment of input. The simulation results are saved into the database for the output component to retrieve and present to SB-WCPSS users.

Figure 1 describes the structure of the SB-WCPSS. Urban domestic water consumptions consist of three types—indoor consumption, turf consumption, and pool consumption for each parcel (box a). The SB-WCPSS user adjusts the inputs of the consumption rates to represent scenarios of different human behavior. The parcel data layer contains population, household, employee, and land use data (box b). The user adjustment of those input values makes it possible to reflect different development scenarios. The climate change input variables provide a way of including climate change impact in the scenario analysis (box c). Finally, SB-WCPSS can accommodate different summary areas for spatial aggregation of water consumption.

2.2.1 *Parcel level consumption (box d)*

Parcel level indoor consumption is calculated from the number of people and per capita water usage rates. The water usage rates vary by land use, therefore, the parcel level daily indoor water consumption is calculated as:

$$WC^{i}_{k,u} = WR^{i}_{u} * N_p * Adj_k \tag{1}$$

where, $WC^{i}_{k,u}$ = daily indoor water consumption for the k^{th} month (gallons), k = 1, 2, … 12 and land use type u; WR^{i}_{u} = per capita Indoor daily water usage rate for land use type u (gallons per capita per day (GPCD)); N_p = number of people/employees/guests; Adj_k = Climate change adjustment for the k^{th} month.

Parcel level monthly indoor water consumption is calculated as:

$$WC^{im}_{k} = WC^{i}_{k,u} * D_k \tag{2}$$

where, WC^{im}_{k} = monthly indoor water consumption for the k^{th} month (gallons), k = 1, 2, … 12; D_k = number of days in the k^{th} month.

Parcel level annual indoor water consumption is calculated as:

$$WC^{iy} = \sum WC^{im}_{k}, \text{ for } k = 1 \ldots 12 \tag{3}$$

where, WC^{iy} = annual indoor water consumption (gallons).

Parcel level turf water consumption is calculated as monthly water consumption rates multiplied by the turf surface area.

$$WC^{tm}_{k} = WR^{t}_{k} * A^{t} * Adj_k \tag{4}$$

where, WC^{tm}_{k} = turf water consumption for the k^{th} month (gallons), k = 1, 2, … 12; WR^{t}_{k} = turf water usage rate per unit area for the k^{th} month (gallons per square foot), k = 1, 2, … 12; A^{t} = turf area (square feet).

Parcel level annual turf water consumption is calculated as:

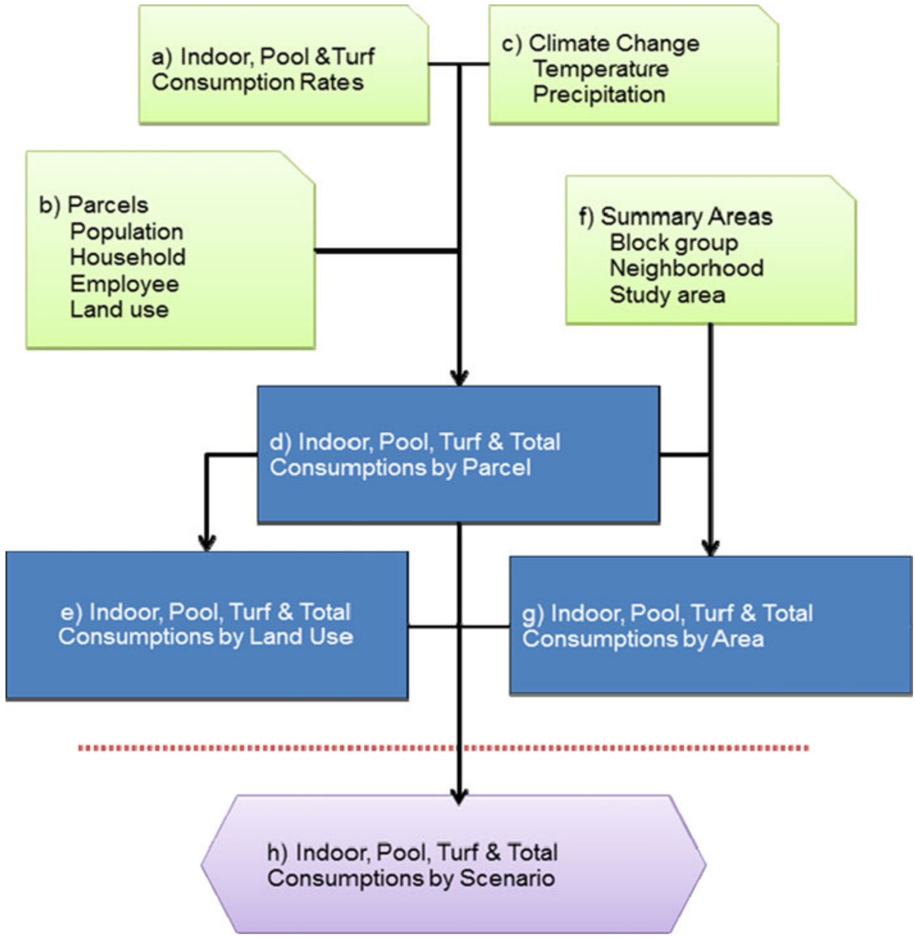
$$WC^{ty} = \sum WC^{tm}_{k}, \text{ for } k = 1 \ldots 12 \tag{5}$$

where, WC^{ty} = annual turf water consumption (gallons).

Pool water consumption calculation takes into account the storage of a pool along with the rate of evaporation.

$$WC^{py} = V^{p} + E^{p} * A^{p} \tag{6}$$

Fig. 1 SB-WCPSS structure



where, WC^{py} = annual pool water consumption (gallons); V^{p} = volume of a pool (gallons); E^{p} = annual pool evaporation rate (gallons per square foot); A^{p} = pool surface area (square foot).

The total annual water consumption for a parcel is finally calculated as:

$$WC = WC^{iy} + WC^{ty} + WC^{py} \quad (7)$$

where, WC = annual total water consumption (gallons).

2.2.2 *Consumption by land use (box e) and by summary area (boxes f and g)*

Parcel level water consumption can then be summarized by land use types (box e), or by different summary areas (boxes f and g). The results can then be analyzed by scenario or multiple scenarios can be compared (box h).

2.2.3 *Climate change inputs*

Literature has shown that climate can be a factor affecting water consumption (Dandy et al. 1997; Guhathakurta and Gober 2007). Before a more robust climate change model is developed we constructed a set of linear regression models to predict water consumption based on ambient temperature and precipitation. Previous research has shown that there is a positive correlation between temperature and water consumption, thus leading to the creation of a linear regression model for use as input into the SB-WCPSS. When there is increased precipitation people use less water (Balling and Gober 2007). Such regression models must be specific to the study site.

We developed the regression models using monthly data in Cincinnati—total water consumption, average of the maximum mean daily temperature, and total precipitation. A calendar year was divided into two 6-month seasons—summer (April–September), and winter (October–March). The seasons are broken by growing versus dormant season because there is not much precipitation from October to March in the study area. The temperature regression model takes the form of:

$$\frac{WC^{i}}{AWC} = a^{T}T^{i} + b^{T} \quad (8)$$

where, WC^{i} = water consumption in month i (gallons); AWC = average monthly water consumption (gallons), derived by calculating the average of the monthly aggregate water consumption for the region for month i.; T^i = average maximum daily temperature for month i; a^T = slope of the temperature regression model; b^T = intercept of the temperature regression model.

The precipitation regression model takes the form of:

$$\frac{WC^i}{AWC} = a^P P^i + b^P \tag{9}$$

where, WC^i = water consumption in month I (gallons); AWC = average monthly water consumption (gallons); P^i = average maximum mean daily temperature for month i; a^P = slope of the precipitation regression model; b^P = intercept of the precipitation regression model.

3 The SB-WCPSS model

The SB-WCPSS interface consists of a display window, a layer list window, and a control panel. Multiple scenarios can be developed and compared (Fig. 2).

3.1 Input variables

A user may adjust input variables to represent different scenarios. Since the model considers three types of water consumption—turf, swimming pool, and indoor water consumption, the input variables are grouped accordingly. Input variables are treated in three ways in CommunityViz—modification of the geometry of a data layer, change of attributes of a data layer, or usage of assumptions. Four land use based indoor water consumption assumptions are developed, which represent per capita daily water usage for single family (SF indoor), multi-family and mixed use (MF MU indoor), resort and casino guests (RE guest indoor consumption), and commercial, industrial, resort and casino, and golf course employees (RE Emp COM IN PF GC indoor) (Fig. 3). Two assumptions are developed for pool water consumption. "Pool Evaporation" is the annual water loss via evaporation measured as gallons per square feet of pool surface. "Pool Depth" is the average depth a swimming pool in feet (Fig. 4). Monthly water consumption assumptions are developed for turf water usage from April till September (Fig. 5). The unit is gallons per square feet of turf surface area.

The effect of climate change is reflected in the change of temperature and/or precipitation from the normal condition. In this model, a user may elect to consider climate change reflected in temperature or precipitation by assigning values for the linear regression model parameters under the "Climate Change" assumptions (Fig. 6). Pa and Pb are the slope and intercept for the precipitation

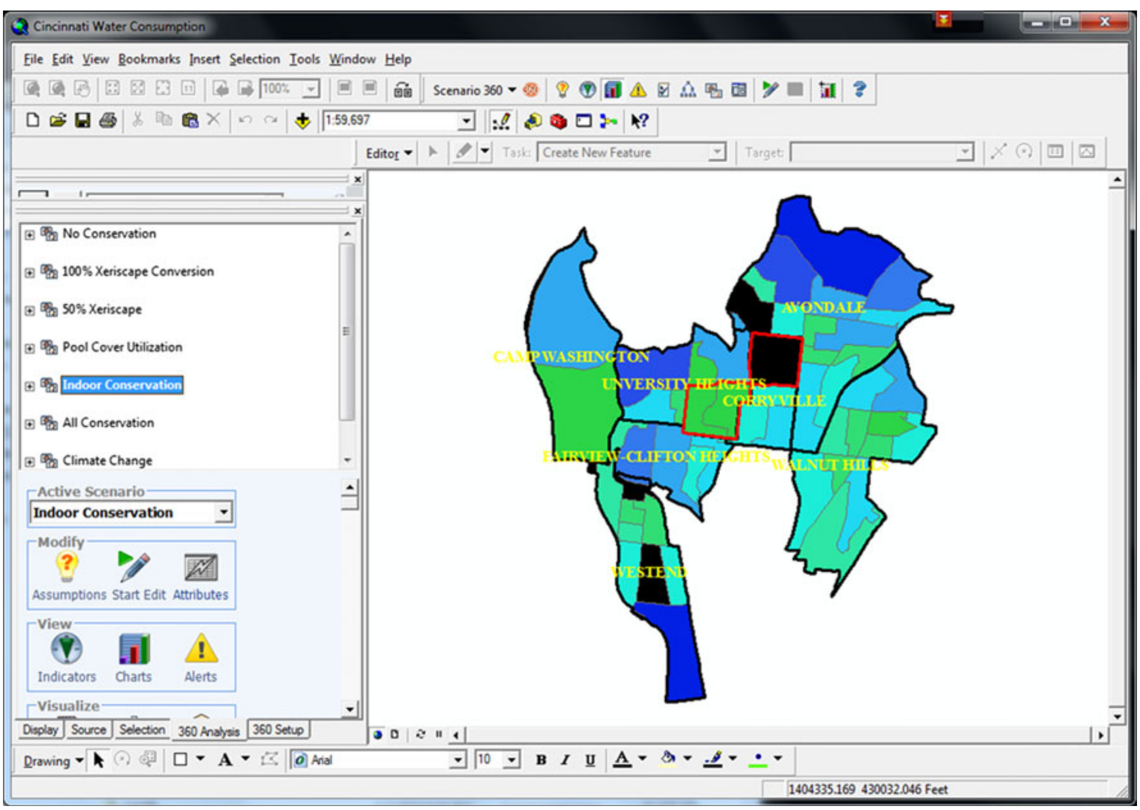


Fig. 2 SB-WCPSS interface

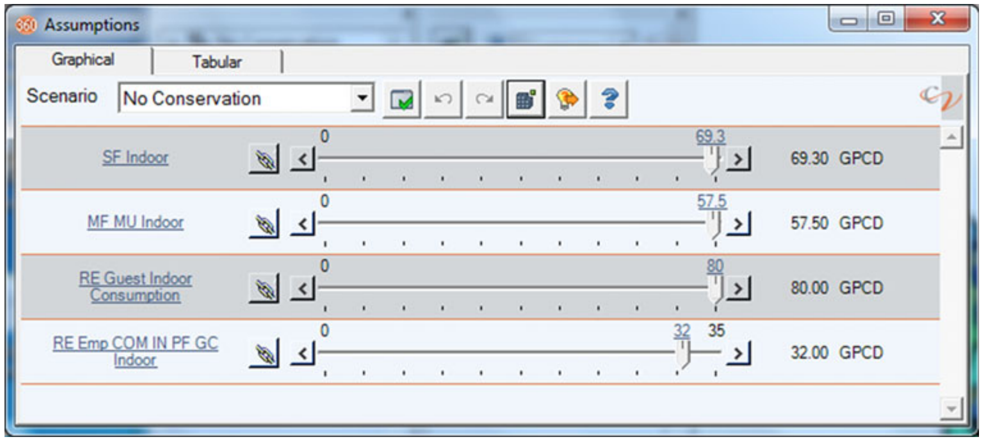


Fig. 3 Input assumptions—indoor water consumption

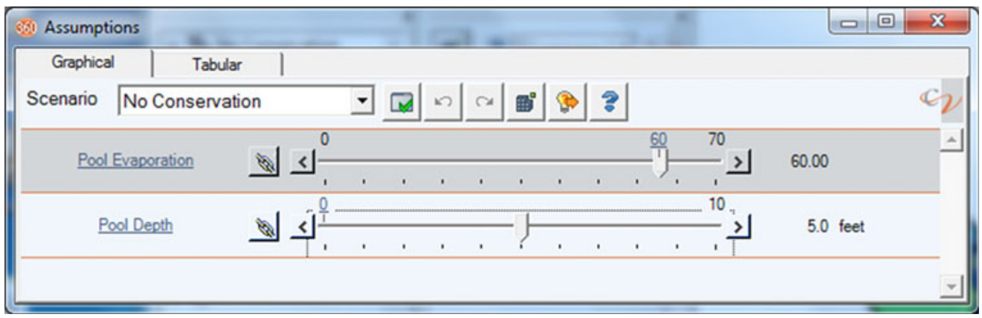


Fig. 4 Input assumptions—pool water consumption (Southern Nevada Water Authority 2008)

Fig. 5 Input assumptions—turf water consumption (Sovocool et al. 2006)

regression model. There are two temperature regression models, one for April–September (TaAS and TbAS) and the other, October–March (TaOM and TbOM). The climate change input has the choice of considering temperature (Temp), precipitation (Prec), or neither (None). We included 12 months for temperature and only considered precipitation for April–September, because there is not much precipitation from October–March in the study area. Precipitation is measured in inches and temperature in Fahrenheit (Figs. 7, 8).

3.2 Dynamic attributes

Dynamic attributes are created for parcels, block groups, and neighborhoods. At the parcel level, daily indoor water consumption is first calculated and then aggregated into monthly and annual totals. Pool consumption is an annual attribute but is only considered for months April through September, since those are months that pools are typically filled. Turf water consumption is first calculated by month and then added to get the annual values. The monthly

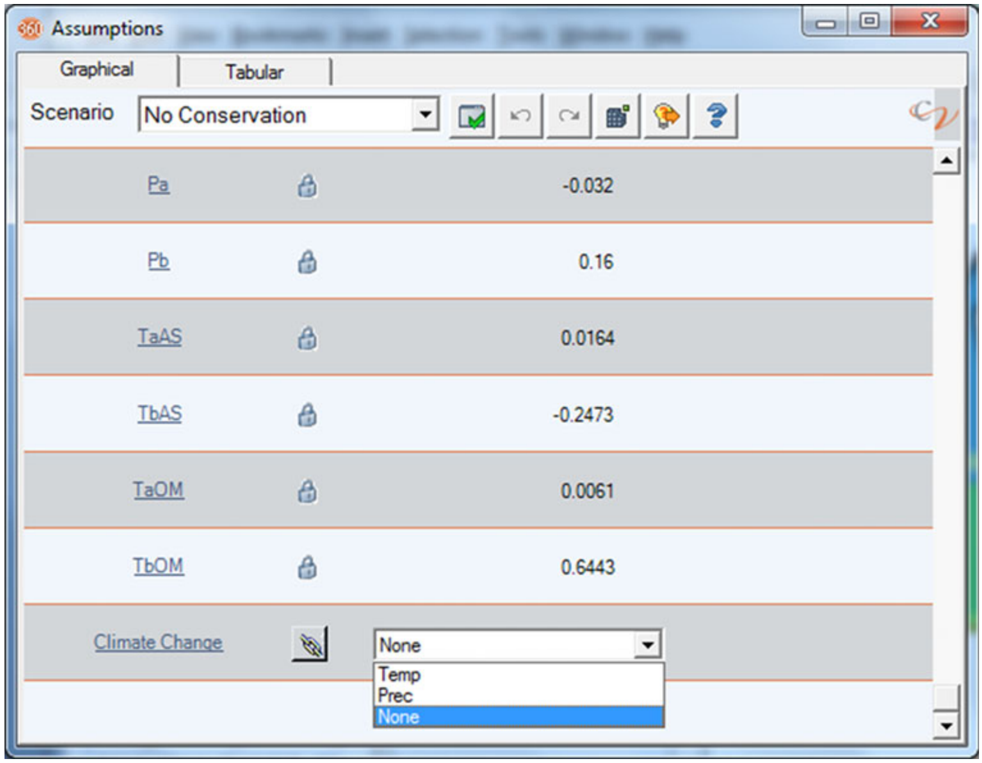


Fig. 6 Input assumptions—climate change linear regression parameters

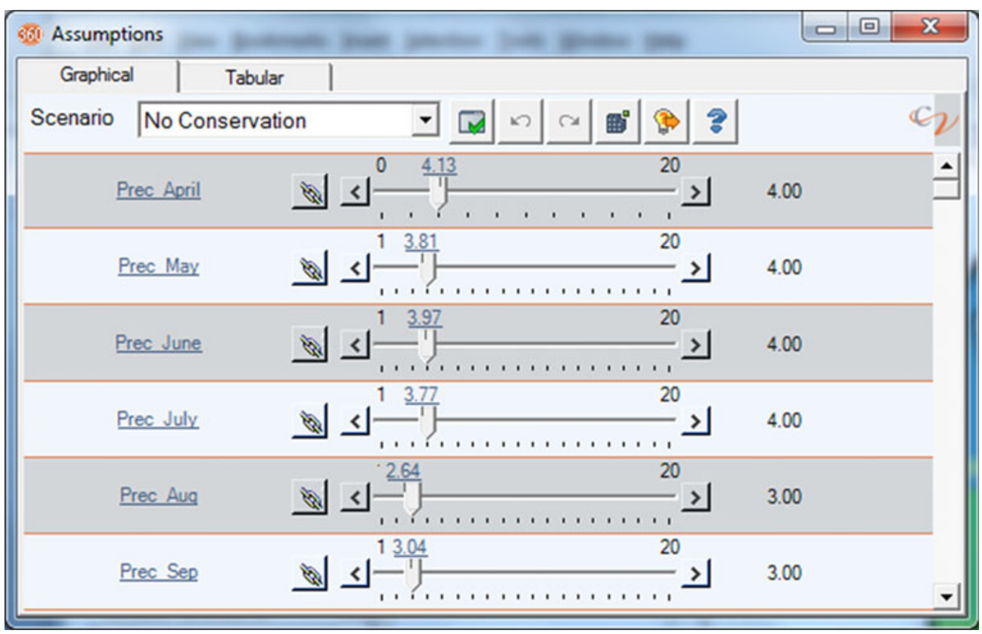


Fig. 7 Input assumptions—total precipitation by month (in inches)

consumptions are only calculated for April through September since those are the months when lawns are more frequently watered aside from precipitation. Annual turf consumption is the sum of the April through September turf consumptions. Figure 9 lists parcel level dynamic attributes. The parcel annual total water consumption can be aggregated spatially by block group and neighborhood.

3.3 Indicators and charts

Indicators and graphs are used to present water consumption results. Their uses in this model include annual water consumption by land use, by neighborhood, and by type for the entire site. Figure 10 lists some of these indicators. Figure 11 displays water consumption by different land uses.

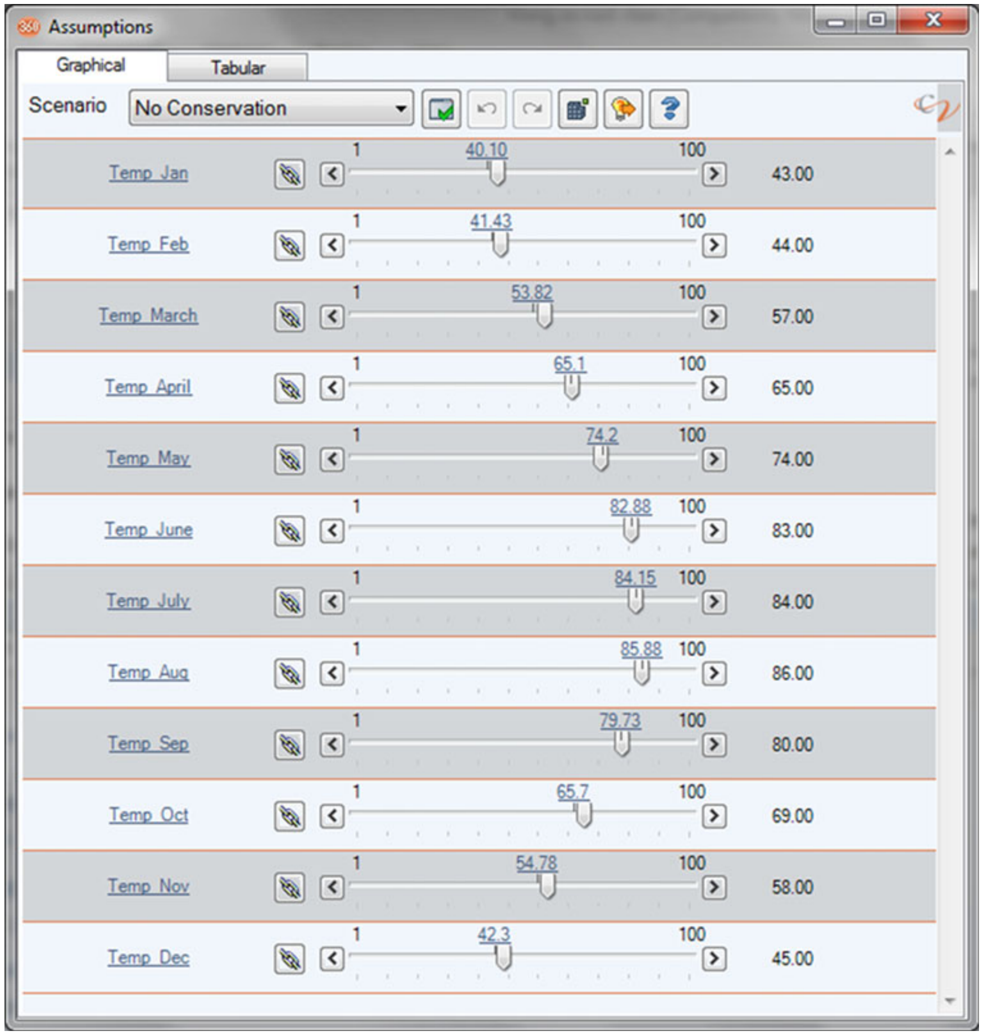


Fig. 8 Input assumptions—average of daily maximum temperature (in Fahrenheit)

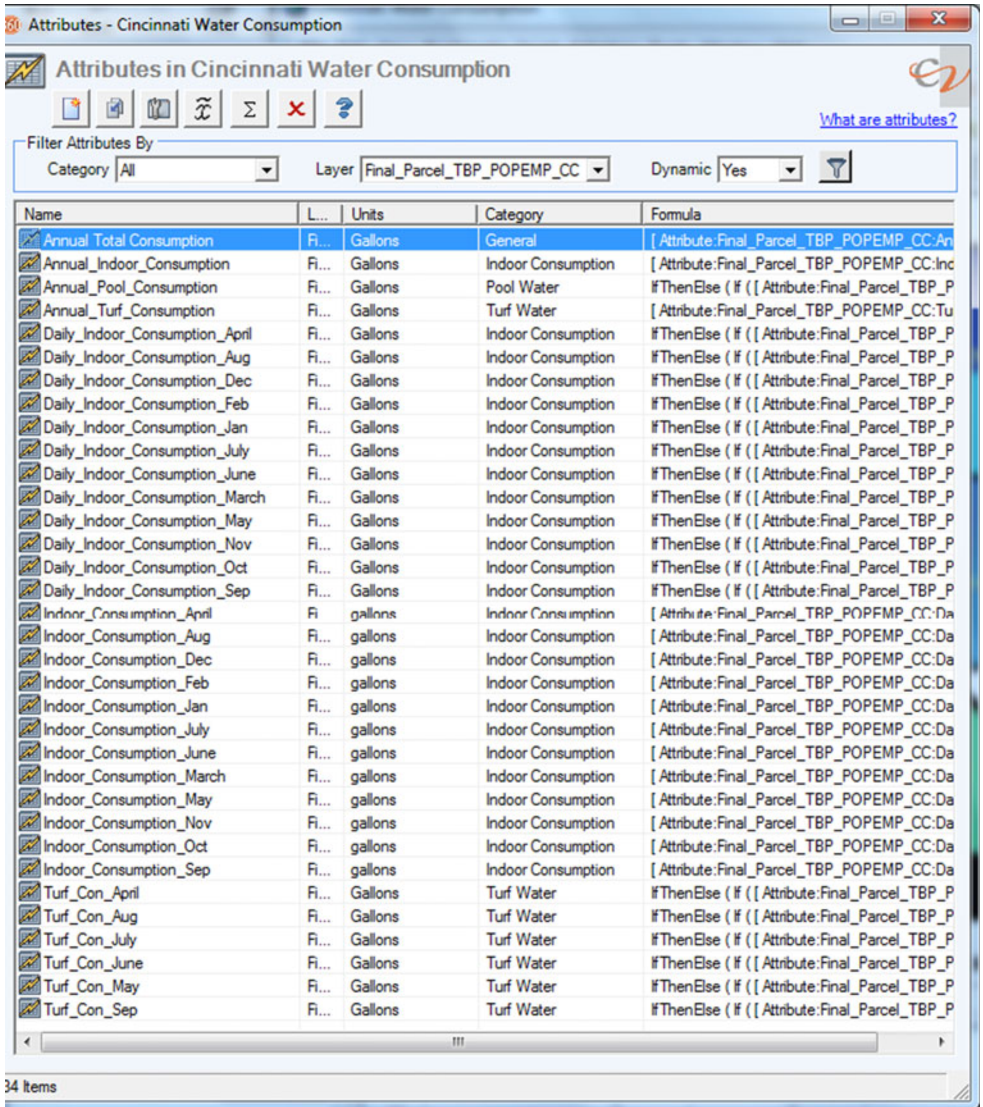
4 Development of scenarios

Scenarios can be developed in three ways; (1) change of water consumption rates; (2) change of population, employees, and land use; and (3) consideration of climate change. As shown in Figs. 3, 4 and 5, water conservations may be represented in different indoor water consumption rates by land use. We select seven scenarios to illustrate the scenario development and comparison. The conservation approaches considered are indoor conservations, xeriscaping, and pool cover utilization.

The first scenario serves as the baseline scenario and we called it "No Conservation". Table 1 displays daily per capital water consumption by land use under this scenario. The values are derived from the literature. In addition, no xeriscaping practice is applied to lawn in the study area and swimming pools are not covered.

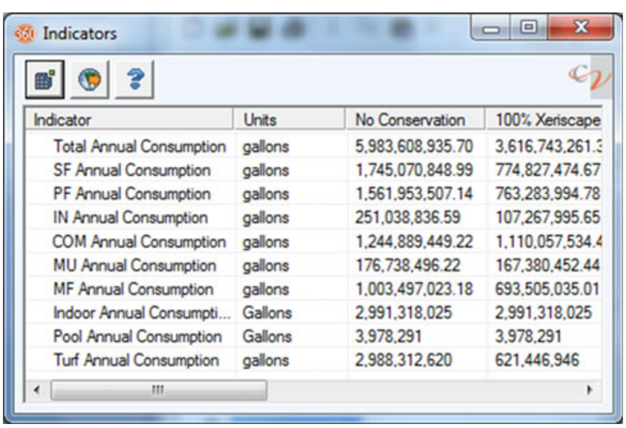
The second scenario is "Indoor Conservation". Table 2 shows possible indoor water conservation methods by land use. We constructed this table to adjust indoor water consumption rate for each type of indoor consumption. Indoor water consumption may apply to toilets, faucets, and leaks on all land use types. The amount of water conserved for each conservation method is derived from Vickers (2001). Benefits from dishwasher water conservation may only apply to residential land uses. Combining both tables may set the basis for adjusting indoor water consumption rate assumptions. Indoor water consumption depends on the number of people who use water and how they use water. In special cases, such as hotels, resorts and casino, the number of guests also affect indoor water consumption. Modification of corresponding attributes of the parcel data layer may represent such change. Though we do not include such change in this scenario. We also assume no other water conservation is applied in the study area.

Water conservation from turf is achieved by reducing turf water usage rates. As an example, xeriscape refers to the conversion of turf to natural landscapes in the region (Sovocool et al. 2006). Studies have shown that such conversion may reduce turf water usage (Fig. 12). We



Name	L...	Units	Category	Formula
Annual Total Consumption	Fi...	Gallons	General	[Attribute:Final_Parcel_TBP_POPEMP_CC:An
Annual_Indoor_Consumption	Fi...	Gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Ind
Annual_Pool_Consumption	Fi...	Gallons	Pool Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Annual_Turf_Consumption	Fi...	Gallons	Turf Water	[Attribute:Final_Parcel_TBP_POPEMP_CC:Tu
Daily_Indoor_Consumption_April	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Aug	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Dec	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Feb	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Jan	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_July	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_June	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_March	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_May	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Nov	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Oct	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Daily_Indoor_Consumption_Sep	Fi...	Gallons	Indoor Consumption	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Indoor_Consumption_April	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Aug	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Dec	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Feb	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Jan	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_July	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_June	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_March	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_May	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Nov	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Oct	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Indoor_Consumption_Sep	Fi...	gallons	Indoor Consumption	[Attribute:Final_Parcel_TBP_POPEMP_CC:Da
Turf_Con_April	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Turf_Con_Aug	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Turf_Con_July	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Turf_Con_June	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Turf_Con_May	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P
Turf_Con_Sep	Fi...	Gallons	Turf Water	IfThenElse (If ([Attribute:Final_Parcel_TBP_P

Fig. 9 Parcel dynamic attributes



Indicator	Units	No Conservation	100% Xeriscape
Total Annual Consumption	gallons	5,983,608,935.70	3,616,743,261.3
SF Annual Consumption	gallons	1,745,070,848.99	774,827,474.67
PF Annual Consumption	gallons	1,561,953,507.14	763,283,994.78
IN Annual Consumption	gallons	251,038,836.59	107,267,995.65
COM Annual Consumption	gallons	1,244,889,449.22	1,110,057,534.4
MU Annual Consumption	gallons	176,738,496.22	167,380,452.44
MF Annual Consumption	gallons	1,003,497,023.18	693,505,035.01
Indoor Annual Consumpti...	Gallons	2,991,318,025	2,991,318,025
Pool Annual Consumption	Gallons	3,978,291	3,978,291
Turf Annual Consumption	gallons	2,988,312,620	621,446,946

Fig. 10 Water consumption indicators

create two scenarios for 100 and 50 % xeriscaping to represent all or half of the lawn in the study area is converted to xeriscaping, respectively.

We include pool cover in the “Pool Cover Utilization” scenario. All swimming pools in the study area use pool covers when the pools are not in use. The “All Conservation” scenario represents the combination of “Indoor Conservation”, “100 % Xeriscape”, and “Pool cover Utilization” scenarios.

To include the effects of climate change on a scenario a user can change the climate change variables (Figs. 7, 8 and 9). If either PREP or TEMP is selected for the climate change assumption, the resulting scenario will present the results of the various types of consumption given the change in climate. Monthly turf water consumption, temperature, and precipitation are all included in the calculation for climate change. The final scenario, “Indoor Conservation with Climate change” reflects an increased temperature by 2.86 ° while maintaining same values for other input variable as that of the “Indoor Conservation” scenario.

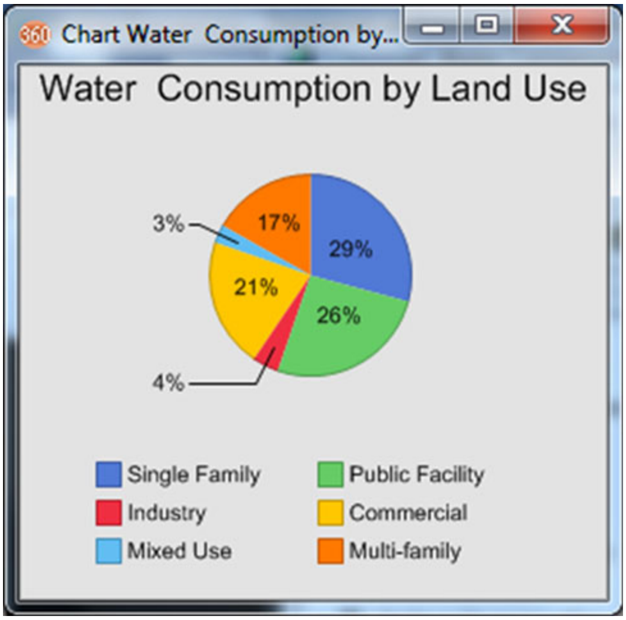


Fig. 11 Chart of water consumption by land use

Table 1 Daily per capita indoor water consumption by land use (gallons)

Land use	Daily per capita water consumption (gallons)	Reference sources
Single family	69.3	AWWARF (1999)
Multifamily	57.5	Vickers (2001)
Commercial	32	Computer Support Group, Inc. (2009)
Industrial	32	Computer Support Group, Inc. (2009)
Public facility	32	Computer Support Group, Inc. (2009)
Mixed use	57.5	Vickers (2001)
Resort and casino	32 (employee)	Computer Support Group, Inc. (2009)
	80 (guest)	Cooley et al. (2007)
Golf course	32	Computer Support Group, Inc. (2009)

5 Results

Figure 13 is a chart of the total water consumption by scenario for the study area. The total annual consumption without any conservation is 5.983 billion gallons per year (BGPY). The largest change in total annual consumption is in the "All Conservation" scenario. The water consumption of the entire site dropped to 2.32 BGPY. This is 3.66 billion gallons less than when non-conservation takes place, a 60 % decrease in consumption. Each scenario does decrease the total annual consumption. 100 % Xeriscape has the second largest decrease to 3.62 BGPY, a 40 % decrease. 50 % xeriscaping decreased 20 % to 4.801 BGPY. Indoor Conservation decreased consumption to 4.69 BGPY, 22 %. Pool cover utilization has the smallest change in consumption for the entire site, a decrease to 5.982 BGPY. Total indoor conservation with climate change is larger than when climate change is not a factor in the scenario. An increase of 374–5.066 BGPY occurred for only a 2.86 °F increase in temperature. There was still a 1.29 BGPY decrease from the no conservation scenario, 22 %.

Each scenario illustrates the potential water savings from a particular water conservation approach. The all conservation scenario had the largest drop in water consumption, which is mostly contributed by adoption of 100 % xeriscaping. This means that using a combination of water conservation methods will save the largest amount of water. However, in order to achieve this goal, each individual citizen needs to make a conscious effort to conserve water.

The climate change scenario was initially expected to increase water consumption above the expected conservation assumptions. The scenario did exhibit this expectation. Therefore, it is likely that with the increase in temperature, water consumption is affected and that needs to be included in public education. The public must know that water consumption increases with climate change and that conservation is that much more important if there are to be resources for future generations.

Regardless of whether or not there is climate change, citizens need to try to conserve water. The conservation will depend on what options they have. If the government provides rebates and incentives for conservation, the public will more likely take advantage of those incentives or rebates to conserve water. Decision makers have an obligation to provide their citizens the information and the tools to reduce water consumption and each individual has the responsibility to conserve water. Maximum conservation as shown in the all conservation scenario is only achievable if citizens and decision makers make the effort to change. This model gives the decision makers the tools they need to find what could happen using different conservation methods. It also can be used to show the public what happens when they conserve and what ways they can conserve. It is both a tool in public education and decision making for water conservation.

6 Concluding remarks

This research extends the capacity of planning for the reduction of water availability by using the GIS planning software CommunityViz to create scenarios based on water

Table 2 Water conserved by indoor water conservation method (gallons per capita per day)

	Toilets	Shower heads	Faucets	Clothes washers	Leaks	Dish washers	Total
Multi-family	10.3	2.8	0.1	0	5.5	0.3	19
Commercial	10.3	0	0.1	0	5.5	0	15.9
Industrial	10.3	0	0.1	0	5.5	0	15.9
Resort and casino employee	10.3	0	0.1	0	5.5	0	15.9
Resort and casino guest	10.3	0	0.1	5	5.5	0.3	21.2
Golf course	10.3	0	0.1	0	5.5	0	15.9
Public facility	10.3	0	0.1	0	5.5	0	15.9
Single family	10.3	2.8	0.1	5	5.5	0.3	24

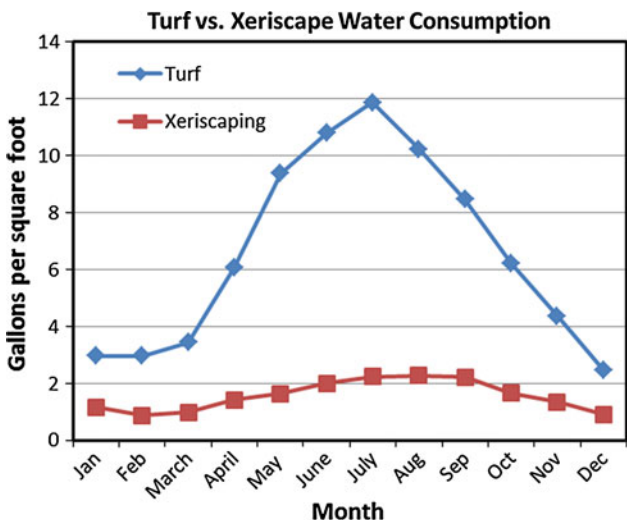


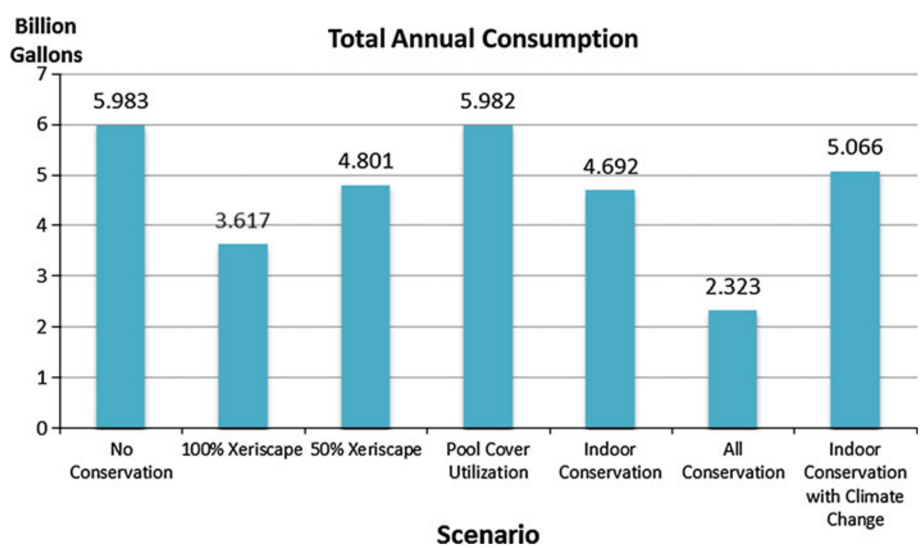
Fig. 12 Comparison of turf and xeriscape water consumption per month (Sovocool 2005)

consumption characteristics per land use. The model was created to use as a way of gauging different options for planning for water resources in the future. It can help encourage community participation, negotiation, and consensus building of multi-interest stakeholders to conserve water, whether it is through changes in development directives, water resource adaptation engineering, or policy enactment. Better planning of water resources can help to develop more sustainable communities in a time when sustainability is increasingly needed. The phrase "think globally, act locally" is as far as we go currently with changing the habits of people to help our environment. This research can take the phrase a step further to "think globally, act locally, start with me!" It can give each individual community member the information they need to change their water consumption habits.

This model gives citizens and decision makers a tool to make decisions about water consumption. Decision makers can use the scenarios to find which water conservation methods may have the greatest effect on their regions. They can decide on incentives or rebates to offer community members to reach a water conservation goal based on the results of the model.

The SB-WCPSS is a simplification of reality. There are several factors that are not included in the model that can affect water consumption rates. Some of these include household income, employment, race and ethnicity,

Fig. 13 Chart of total annual water consumption by scenario



building structure age, commercial structure type (i.e. restaurant vs. clothing store), and ownership of private or public pools. Also, the consumption model does not include information such as, customers at commercial establishments per day, children per school, or patients per hospital.

Ideally, the model would include everything that could affect water consumption rates in significant proportions. However, there are some things that cannot be quantitatively simulated. Many of the factors are not considered due to time constraints. Others are not included because the data are not available. For example, behavior can affect water consumption. One person in the city may do everything in her power to conserve water while another may use everything she can get. This is hard to factor into a model. Upon learning about water conservation methods, not everyone will actually try to conserve water. A modification of the model may include an input of percentage of people in the study area will participate in water conservation. Nevertheless, the development of the SB-WCPSS has shown the potential to spatially model water consumption and analyze water conservation effectiveness.

There are other limitations of the model besides it being a simplification of reality. The model uses estimates of water consumption per land use, rather than actual per parcel usage. To create the most accurate representation, it is ideal to use the actual data per individual household because metropolitan averages can be misleading and consumption of different households can vary considerably (Troy and Holloway 2004). Localized data can also be used to develop and verify simulation models. It is encouraging to see that the modeling results are consistent with the literature that water consumption is related to climate change. For example, the comparison of the indoor conservation scenario to the indoor conservation with climate change scenario shows a 374 million gallon increase in water consumption.

Further development of the SB-WCPSS could expand the model to include traffic, drinking water, wastewater, storm water, air quality (black carbon and PAH), and climate model (precipitation and temperature). For example, the SC-WCPSS model has the ability to support other water resource management. For example, the spatial distribution of water consumption can determine the adaptive usage of existing infrastructure. Increased vacancies will decrease the rate water is used in potable water pipes and can affect water quality as well, allowing stagnant water to sit in pipes rather than be used be citizens. Additionally, water consumption can be linked to wastewater. By understanding the amount of water that will be used in an area, the amount of water that will flow into a wastewater system may be predicted. Similarly, understanding spatial pattern of water consumption may indicate where wastewater and potable water systems need to be expanded or modified. In a system analysis that includes these additional model types, a planning–modeling–optimization process would aim to define future scenarios of urban transportation and water infrastructure, to quantify their tradeoffs against multi-criteria of greener and smarter developments, and subsequently to optimize the water–energy–climate values of an urban infrastructure development plan.

Acknowledgments The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's administrative review and has been approved for external publication. Any opinions expressed in this paper are those of the author(s) and do not necessarily reflect the views of the agency; therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use. The authors are very grateful to the editors and the anonymous reviewers for their insightful comments and suggestions.

References

American Water Works Association Research Foundation (AWWARF) (1999) Residential water use summary 1999. http://www.aquacraft.com/Publications/residents.htm. Accessed 3 May 2010

Avin UP, Dembner JL (2001) Getting scenario-building right. Planning 67(11):22–27

Balling RC Jr, Gober P (2007) Climate variability and residential water use in the city of Phoenix, Arizona. J Appl Meteorol Climatol 46:1130–1137

Burgess A (2010) Promoting domestic water conservation through the utilization of a scenario-based planning support system. Master's THESIS. University of Cincinnati, Cincinnati

Computer Support Group, Inc (2009) Water consumption calculator. Computer Support Group. http://www.csgnetwork.com/waterusagecalc.html. Accessed 31 Oct 2009

Cooley H, Hutchins-Cabibi T, Cohen M, Gleick PH, Herberger M (2007) Hidden Oasis: water conservation and efficiency in Las Vegas. Pacific Institute and Western Resource Advocates, Oakland

Cummings R (2007) Engaging the public through narrative based scenarios. In: Hopkins LD, Zapata MA (eds) Engaging the future: forecasts, scenarios, plans, and projects. Lincoln Institute of Land Policy, Cambridge, pp 243–260

Dandy G, Nguyen T, Davies C (1997) Estimating residential water demand in the presence of free allowances. Land Econ 73(1): 125–139

Deviney FA Jr, Brown DE, Rice KC (2012) Evaluation of bayesian estimation of a hidden continuous-time Markov chain model with application to threshold violation in water-quality indicators. J Environ Inform 19(2):70–78

Fletcher TD, Deletic A (2008) Data requirements for integrated urban water management. UNESCO, Paris

Geertman S, Stillwell J (2003) Planning support systems: an introduction. In: Geertman SS, Stillwell J (eds) Planning support systems in practice. Springer, New York, pp 3–22

Greater Cincinnati Water Works (2010) Monthly aggregate water consumption. Greater Cincinnati Water Works, Cincinnati

Guhathakurta S, Gober P (2007) The impact of the phoenix urban heat island on residential water use. J Am Plan Assoc 73(3):317–329

Guo P, Huang GH (2009) Two-stage fuzzy chance-constrained programming: application to water resources management under dual uncertainties. Stoch Environ Res Risk Assess 23:349–359

Hopkins LD, Zapata MA (2007) Engaging the future: forecasts, scenarios, plans and projects. Lincoln Institute of Land Policy, Cambridge

Randolph J (2004) Environmental land use planning and management. Island Press, Washington, DC

Kenny JF, Barber NL, Hutson SS, Linsey KS, Lovelace JK, Maupin MA (2009) Estimated use of water in the United States in 2005. United States Geological Survey, Reston

Klosterman RE (2001) Planning support systems: a new perspective on computer-aided planning. In: Brail RK, Klosterman RE (eds) Planning support systems: integrating geographic information systems, models, and visualization tools. ESRI Press, Redlands

Klosterman RE (2007) Deliberating about the future. In: Hopkins LD, Zapata MA (eds) Engaging the future: forecasts, scenarios, plans, and projects. Lincoln Institute of Land Policy, Cambridge, pp 199–220

Li YP, Huang GH, Chen X (2009) Multistage scenario-based interval-stochastic programming for planning water resources allocation. Stoch Environ Res Risk Assess 23:781–792

Li YP, Huang GH, Nie SL (2010) Planning water resources management systems using a fuzzy-boundary interval-stochastic programming method. Adv Water Resour 33:1105–1117

Li YP, Huang GH, Nie SL, Chen X (2011) A robust modeling approach for regional water management under multiple uncertainties. Agric Water Manag 98:1577–1588

Liu Z, Tong TY (2011) Using HSPF to model the hydrologic and water quality impacts of riparian land-use change in a small watershed. J Environ Inform 17(1):1–14

National Weather Service (2010) Archived climate data—NWS Wilmington. http://www.erh.noaa.gov/iln/lcdpage.htm. Accessed 20 Feb 2010

Schreck B, Farber H (2009) A water supply crisis or a water management crisis? J Am Water Works Assoc 33:458–469

Sipes JL (2003) Visualizing community form. Landsc Archit 93: 56–97

Southern Nevada Water Authority (2008) Pools and spa tips. Southern Nevada Water Authority. http://www.snwa.com/html/cons_tips_pool/html. Accessed 15 Dec 2009

Sovocool KA (2005) Xeriscape conversion study final Report. Southern Nevada Water Authority. http://www.snwa.com/assets/pdf/xeri_study_final.pdf. Accessed 15 Dec 2009

Sovocool KA, Morgan M, Bennett D (2006) An in-depth investigation of xeriscape as a water conservation measure. American Water Works Association Journal 98(2):82–93

The Orton Family Foundation (2004) An introduction to GIS planning support software, version 1.0. The Orton Family Foundation, Boulder

Troy P, Holloway D (2004) The use of residential water consumption as an urban planning tool: a pilot study in Adelaide. J Environ Plan Manag 47(1):97–114

United States Environmental Protection Agency (2009) water resource adaptation program. http://www.epa.gov/nrmrl/wswrd/wqm/wrap/. Accessed 30 April 2009

Vickers A (2001) Handbook of water use and conservation. Water Plow Press, Amherst

Wang S, Huang GH, Lu HW, Li YP (2010) An interval-valued fuzzy linear programming with infinite a-cuts method for environmental management under uncertainty. Stoch Environ Res Risk Assess 25:211–222

Zhao H, Zhang J, James RT, Laing J (2012) Application of MIKE SHE/MIKE 11 model to structural BMPs in S191 Basin, Florida. J Environ Inform 19(1):10–19