Water Conservation Techniques and Graywater Reuse at the Single Household Level

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Abstract

Water has become a scarce resource on this earth. The population of the world is increasing tremendously while the earth's water resources are limited. Many efforts have been put forth to innovate water conservation measures. This work summarizes some analyses performed to investigate the effect and feasibility of applying different water conservation techniques in a US household with an emphasis on the use of graywater in both toilet flushing and landscape irrigation. Some outdoor and indoor conservation techniques are included such as xeriscaping, low-flow toilets, and graywater reuse for toilet flushing and landscape irrigation. The analysis was performed on a house of 3 residents. Twelve conservation scenarios were run through a model developed using the STELLA software (Systems Thinking in an Experimental Learning Lab with Animation). The model outputs are the total amount of potable water used per year and the total amount of wastewater discharged per year. The model results were evaluated and compared based on a cost-benefit analysis. Considering both the annual household savings and the payback period, the scenario which included all water conservation measures as well as graywater usage was the optimum. The optimum scenario achieved annual water savings of 93,000 gallons, which is about 50% of the annual water consumption in the base scenario. The graywater usage was responsible for about 35% of those water savings. The results of this study suggests that water conservation measures can be economically feasible in water scarce areas and stand to save homeowners a significant amount of money in the long run.

Introduction

Water is a precious resource that needs to be utilized in a wise manner in order to optimize its usage. Many areas of the world are suffering from limited water supplies and severe droughts. Due to the finite nature of water, neither water nor wastewater can be considered wastes. They should be considered the same as any other commodity of economic value.

The burden lies on the users to apply water conservation and reuse techniques to minimize the per capita water consumption. The reason is that users are the ones who trigger the whole process to occur. Measures of conservation and reuse at the household should be considered more seriously since the cumulative effects of such will be of great significance to the community as a whole.

This paper looks at the effects of applying various outdoor and indoor water conservation measures at the household level. Examples of the conservation measures are using low-flow toilet flushing boxes, low-flow appliances, and utilizing graywater in toilet flushing and yard irrigation.

Literature Review

In the face of increasing water scarcities, the first and foremost priority should be given to the reduction in water consumption. This should be obvious since reduction is the cheapest and safest way of optimization. A parallel model for water use may be drawn from the field of solid waste management. For example, the USEPA has set a hierarchy for solid waste management, which from top to bottom is: 1) Reduction, 2) Reuse, 3) Transformation, and 4) Disposal. This hierarchy means that the effort should be put on reduction, then reuse, and so on. The same should apply to the water management sector. According to that, water conservation and water reuse should be given a priority. The unique thing about conservation and reuse is that both of them can be practiced at the household level. One benefit of the reuse at the household level is that a third conveyance network will not be needed.

For many years, water recycling has been neglected for socio-economic reasons (Surrendran, 1998). This is no longer the case because the water shortage problem is obvious and treatment technology has evolved tremendously. Therefore, the anticipated benefits of reuse and recycling should not be underestimated. The interest in the reuse of water is increasing due to several factors. One is the water shortage due to low amounts of rainfall along with high evaporation rates, which is the case in countries like Australia (Eriksson et. al., 2002). Another reason can be high water demands from the size of the population, which is the case in countries like Japan (Eriksson et. al., 2002). A third reason can be the environmental and economical considerations behind the reuse process. Living in a remote area where wastewater collection or potable water network are not available can be a fourth reason. This is one of the cases where the use of graywater becomes of significant value.

Graywater Definition. The 2000 edition of The Uniform Plumbing Code defines graywater as "untreated household wastewater which has not come into contact with toilet wastes. Graywater includes used water from bathtubs, showers, bathroom, wash basins, and water from clothes washing machines and laundry tubs. It shall not include waste water from kitchen sinks or dishwashers". This is the definition that has been used in this study.

Graywater Quantities. Each household produces significant amounts of graywater. The graywater quantities generated at an average US household can be obtained from a study conducted by the American Water Works Association entitled as "Residential End Uses of Water". The graywater generation rates as calculated from the data in the study ranged from 33 to 45 gal/capita/d which averaged at 38 gal/capita/d. This number constitutes about 56% of the total indoor use and about 23% of the total water consumption in a household. Several other studies have numbers in this range. A report produced by the City of Los Angeles (City of LA, 1992) revealed that if the total available graywater is used in a household, the amount of water savings would be approximately 50 percent. This number was estimated from eight graywater sites in which the potential demand for graywater used ranged from 13 to 65 percent.

Methodology

The goal of this study is to investigate the effect of various water conservation techniques (indoor and outdoor) at the household level along with the effect of using graywater in landscape irrigation and toilet flushing. In order to achieve that goal, twelve scenarios were set up (Table 1). Each scenario was tested using a model developed at the Harold Short Lab at Colorado State University. The model works on a software called STELLA (Systems Thinking in an Experimental Learning Lab with Animation). A schematic representation of the model is shown in Figure 1. The household size adopted for the analysis was a 3-resident household size, which is about the average household size in the United States.

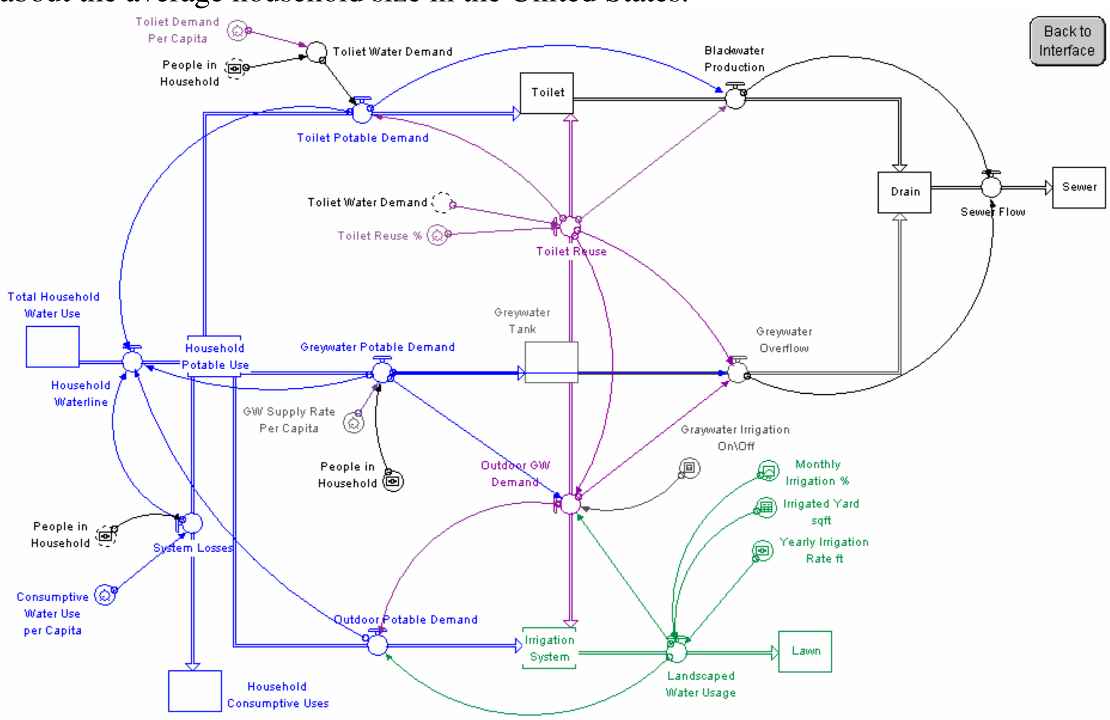

Figure 1. Schematic representation of the Stella model used in the study

The scenarios tested in this study are shown in Table 1. They were designed in a way that shows the effect of each measure on the amount of potable water used and the amount of wastewater discharged to the wastewater treatment plant.

Table 1. Scenarios Used in the Study

Outdoor / **Indoor**	Typical – No outdoor conservation (30” per year)	Water conservation (22” per year)	Xeriscape (1000 ft^2 of turf at 22” & 3000 ft^2 of xeriscape plants)	Xeriscape + GW irrigation + GW toilet flushing (1000 ft^2 of turf at 22” & 3000 ft^2 of xeriscape plants)
Typical – No conservation	1 (Base)	2	3	4
Low-flow toilets*	5	6	7	8
Low-flow Toilets/appliances	9	10	11	12

* Low-flow toilet demand: 8 gal/capita/day, vs typical at 25 gal/capita/day

The model inputs and outputs are shown in Table 2. The major assumptions used in the model are: 1) Precipitation does not affect the irrigation demand; 2) Three residents per household; 3) All household bathrooms are connected to the graywater system; 4) Graywater includes wastewater generated from showers, bath sinks, and laundry, 5) Priority for graywater use is given to toilet flushing

Table 2. Inputs and Outputs for the Model

Model Inputs	**Model Outputs**
• Number of people per household • Toilet demand per capita • Graywater use per capita • Water consumption for drinking • Irrigation rate per year • Evapotranspiration values each month • Area of irrigation	• Total amount of potable water used per year • Total amount of wastewater discharged per year

The water use categories used in the model and their corresponding values are shown in Table 3. All values can be changed by the model user.

Table 3. Water Use Categories Used in the Model

Category	Demand*
Black water - Base scenario - Low flow toilets scenario	 25 gal/cap/day 8 gal/cap/day
Graywater - Base scenario - Low-flow appliaces scenario	 75 gal/cap/day 50 gal/cap/day
Yard irrigation (4000 ft^2) - Base scenario - Water conservation scenario - Combination of turf grass (1000 ft^2) and xeriscaping (3000 ft^2)	 30" per year 22" per year 22" for turf grass and 12" for xeriscape
Drinking water	1 gal/cap/day

* All water demands can be changed by user

Results and Discussion

The model output values, which are the water use and the wastewater discharged to the sewer system, are shown in Table 4. The table also shows the corresponding water and wastewater bill values based on the new water demands.

Table 4. Model Results (Water, Wastewater, & Lawn Use; Water and Wastewater Bill)

Scenario	Water Use (gal/year)	WW/yr (gal/year)	Lawn (gal/year)	Water bill ($/year)	WW bill ($/year)	Total bill ($/year)
1	171382	97200	2440	214	233	447
2	151849	97200	1789	190	233	423
3	145758	97200	1586	182	233	415
4	108301	59743	1586	135	143	278
5	154858	80676	2440	194	194	388
6	135325	80676	1789	169	194	363
7	129234	80676	1586	162	194	356
8	108093	59535	1586	135	143	278
9	130558	56376	2440	163	135	298
10	111025	56376	1789	139	135	274
11	104934	56376	1586	131	135	266
12	78694	30136	1586	98	72	170

The annual water use (column two in Table 4) are shown in Figure 2. The figure shows that scenarios with graywater reuse (4, 8, and 12) show significantly lower water use per year than the other alternatives. Neglecting cost considerations, it would appear that Scenario 12, which includes all indoor and outdoor conservation practices listed in this analysis, would be the best system in terms of water conservation.

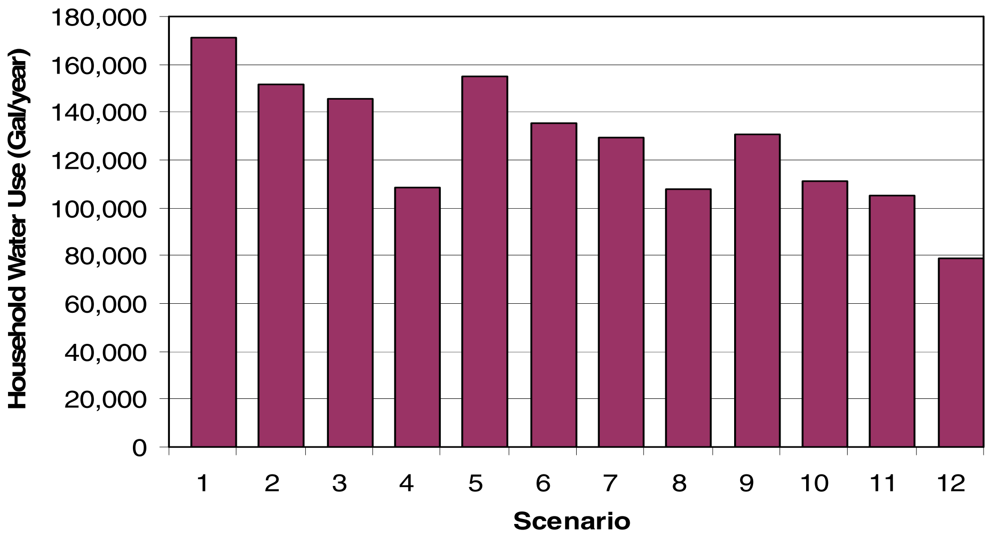

Figure 2. Annual household water use for each scenario

In terms of cost savings, Table 5 shows the annual total water/wastewater and savings compared to the base scenario along with the annual potable water use. The annual water savings (Column 4 in table 5) are represented in Figure 3. It is obvious that the highest water savings are achieved using all indoor and outdoor water conservation measures along with graywater application.

Table 5. Total Water/wastewater Bill and Water Savings Compared to Base Scenario

Scenario	Water Use (gal/year)	Total Annual water/wastewater bill ($/year)	Water Savings compared to base scenario ($/year)
1 (Base)	171382	447	0
2	151849	423	24
3	145758	415	32
4	108301	279	169
5	154858	387	60
6	135325	363	85
7	129234	355	92
8	108093	278	170
9	130558	299	149
10	111025	274	173
11	104934	266	181
12	78694	171	277

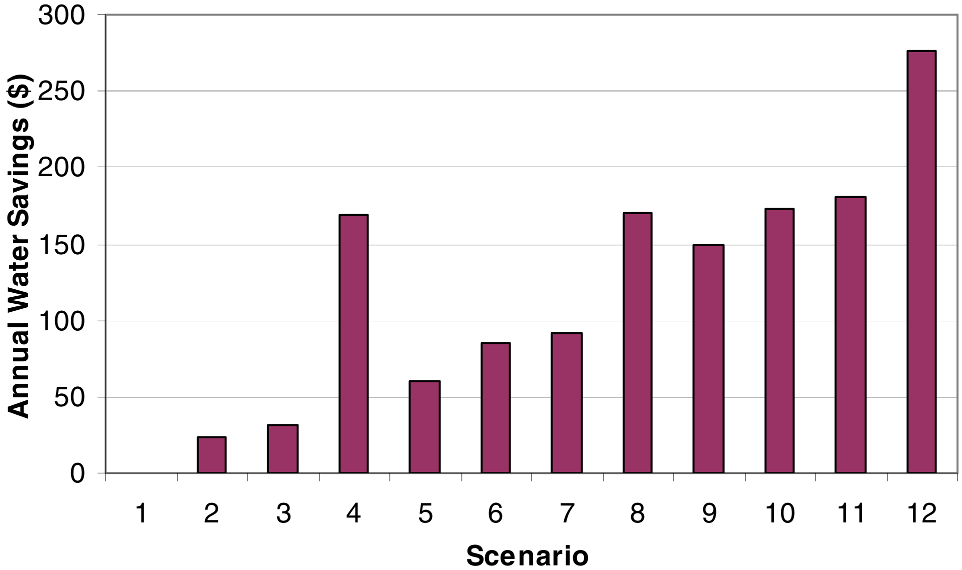

Figure 3. Annual water savings for each scenario

For Scenario 12, graywater is responsible for about 35% of the achieved savings. For the other graywater scenarios; 4 and 8, graywater is responsible for 81% and 46% of the savings shown in Table 6. In terms of the pay-back period, the cost of a system installed at a residential household ($500) was used to determine the payback period. The payback periods of scenarios involving graywater are shown in Table 6.

Table 6. Payback Periods and Contribution of Graywater to Savings

Scenario	Savings from Graywater Reuse ($)	Simple Payback Period (years)	% of Total Savings coming from Graywater Reuse
4	137	3.29	81
8	77	5.83	46
12	96	4.7	35

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