Appendix B: Urban Water Conservation and Efficiency Methodology

This cost-effectiveness assessment examines the costs and savings of residential and non-residential water conservation and efficiency measures as well as distribution system leak detection programs. Data sources include end-use and field studies, expert knowledge, market price search, and other resources. Water savings from fixtures reflect the difference in water use between current efficiency standards or certified water-efficient products and the inefficient models that exists in homes. For example, the average water use for clothes washers in California is 36 gallons per load (DeOreo et al. 2011). This figure is compared to an ENERGY STAR-certified clothes washer with an integrated water factor of 2.9 – 3.5.[1] For a washer with a capacity of 4.3 cubic feet, this factor translates to approximately 16 gallons per load. Thus, the estimated water savings is 20 gallons per load. Based on assumptions about the average number of loads of laundry washed per year, we estimate that replacing an old washer with a high water-efficiency model saves 7,000 gallons of water annually. Details on assumptions for each water conservation and efficiency measure are contained in Tables 1, 2, and 3.

[1] The integrated water factor (IWF) is the water performance metric for clothes washers. It is the ratio of the total weighted per-cycle water use for all wash cycles (in gallons) to the washer capacity (in cubic feet). The lower the water factor, the more water-efficient the washer.

Table 1.

Indoor Residential Water Efficiency Measures

	Value	Units	Comments	Sources
Interest rate (discount rate)	6%		Assumed to be the same as that of supply options	
Wastewater rate (residential)	3.49	$/kgal	Calculated; population-weighted from various locations	
Number of people per household	2.95	persons/household	2010-2014 average	US Census Bureau n.d.
Electricity for water heating	5%			EIA 2009
Natural gas for water heating	95%			EIA 2009
Electricity price (residential)	0.16	$/kWh		EIA 2014a
Natural gas price (residential)	1.13	$/therm		EIA 2014b
Energy required to heat 1 gal by 1 °F for electricity	0.00271	kWh/gal/°F	Calculated; assume 90% efficiency	
Energy required to heat 1 gal by 1 °F for natural gas	0.000128	therms/gal/°F	Calculated; assume 65% efficiency (note that ENERGY STAR' energy factor for >55 gallons of gas storage water heaters is at least 77%)	
Toilets				
Flush volume for old conventional toilets	3.5	gal/flush/device		DeOreo et al. 2011
Flush volume for conventional toilets	1.6	gal/flush/device		Hauenstein et al. 2013

Flush volume for high efficiency toilets	1.28	gal/flush/device		CEC 2015
Number of toilet flushes	4.76	flushes/person/day		DeOreo et al. 2011
Number of toilets per household	2.4	toilets/household		DeOreo et al. 2011
Estimated useful life	25	years		Koeller 2005
Price of inefficient toilets	$230-$320	$/device		Google Shopping; Amazon
Price of HETs	$210-$460	$/device		Google Shopping; Amazon
Showerheads				
Flow rate of conventional showerheads	2.5	gal/min		US EPA 2015b
Efficient shower flow rate	2.0	gal/min		Steffensen 2015
Number of showerheads per household	2.21	showerheads/household		McNeil et al. 2008
Shower duration	8.7	min/shower		DeOreo et al. 2011
Use of showers	1.97	shower/ day-household		DeOreo et al. 2011
Water heating temperature increase	40	°F	Assuming 65°F inlet and 105°F average use	
Estimated useful life	10	years		PG&E 2014
Price of inefficient showerheads	$19-$30	$/device		Google Shopping; Amazon

Price of high efficiency showerheads	$17-$37	$/device		Google Shopping; Amazon
Clothes Washers				
Top load washers water use	36	gal/load/machine		DeOreo et al. 2011
Efficient front load washers water use	16	gal/load/machine	Calculated from the assumed capacity of 4.3 cu./ft. and the efficiency standard.	US EPA 2015a
Percent of laundry water use that is hot water	40%			
Water heating temperature increase	55	°F	Assuming 65°F inlet and 120°F average hot water temp	
Estimated useful life	14	years		CEC 2003
Price of inefficient clothes washers	$360-$480	$/device		Google Shopping; Amazon
Price of efficient clothes washers	$640-$920	$/device		Sears; Sears Outlet
Dishwashers				
Water use for inefficient dishwasher	6.7	gal/ load		Hoak et al. 2008
Water use for water efficient dishwasher	3.5	gal/load		US EPA 2015c
Average energy use (inefficient)	0.76	kWh/load		Hoak et al. 2008
Average energy use (efficient)	0.35	kWh/load		Hoak et al. 2008

Loads per day	0.35	loads/day		DeOreo et al. 2011, p. 206
Estimated useful life	15	years		US DOE 2014
Price of inefficient dishwashers	$250-$350	$/device		Lowe's
Price of water efficient dishwashers	$540-$630	$/device		Google Shopping; Amazon

Table 2.

Indoor Non-Residential Water Efficiency Measures

	Value	Units	Comments	Sources
Interest rate (discount rate)	6%		Assumed to be the same as that of supply options	
Wastewater rate (CII)	4.24	$/kgal	Calculated; population-adjusted from various locations	
Electricity share for water heating	8.5%		Adjusted to account for waste heat recovery system	SBW Consulting 2007
Natural gas share for water heating	91.5%		Adjusted to account for waste heat recovery system	SBW Consulting 2007
Electricity price (CII)	0.16	$/kWh		EIA 2014a
Natural gas price (CII)	0.89	$/therm		EIA 2014b
Energy required to heat 1 gal by 1 °F for electricity	0.00271	kWh/gal/°F	Calculated; assuming 90% efficiency	
Energy required to heat 1 gal by 1 °F for natural gas	0.000128	therms/gal/°F	Calculated; assuming 65% efficiency	
Non-farm employment (2015)	16,051,500		Calculated for the annual average	Bureau of Labor Statistics n.d.
Business days	260	days/year		

Toilets				
Flush volumes			Same as residential models	
Stock of commercial toilets installed in California	4,600,000	toilets		Hauenstein et al. 2013
Toilet water use by employee	2.6	flushes/person-day	Does not include visitors	Gleick et al. 2003
Number of toilet flushes	9.07	flushes/ business day/device	Calculated	
Estimated useful life	12	years		Hauenstein et al. 2013
Price of inefficient toilets	$230-$320	$/device		Google Shopping
Price of HETs	$210-$460	$/device		Google Shopping
Urinals				
Flush volume of stock of conventional urinals	0.71	gal/flush	Assuming that 42% of urinals consume 1.0 gpf and 58% consume 0.5 gpf	Hauenstein et al. 2013
Flush volume of high efficiency urinals	0.125	gal/flush		Hauenstein et al. 2013
Number of flushes	18	flushes/business day		Hauenstein et al. 2013
Estimated Useful Life	12	years		Hauenstein et al. 2013
Price of inefficient urinals	$100-$160	$/device		Google Shopping
Price of high efficiency urinals	$170-$330	$/device		Google Shopping

Showerheads				
Flow rates			Same as residential models	
Water heating temperature increase	40	°F	Assuming 65°F inlet and 105°F average use	
Daily usage	32	min/ business day	Assuming 8 min shower, 4 times/device	CUWA 2015
Business days	270	days/year		CUWA 2015
Estimated Useful life	5	years		CUWA 2015
Price of inefficient showerheads	$19-$30	$/device		Google Shopping; Amazon
Price of high efficiency showerheads	$17-$37	$/device		Google Shopping; Amazon
Faucet aerators				
Water savings	1.2	gal/min	Assuming from 2.2 gpm to 1.0 gpm device	
Daily usage	5	min/ business day	Assuming each hand washing event is 15 sec, 20 uses	CUWA 2015
Estimated useful life	3	years	Assuming is the same as public lavatory faucets	Singh et al. 2015
Price of device	$2-$9	$/device		Google Shopping
Pre-rinse spray valves				
Water savings	19.1	gal/day/device		SBW Consulting 2007
Electric energy savings	596	kWh/year		SBW Consulting 2007
Natural gas energy savings	26.2	therms/year		SBW Consulting 2007

Estimated Useful life	5	years		SBW Consulting 2007
Price of inefficient device	$50-$100	$/device		Google Shopping
Price of efficient device	$50-$190	$/device		Google Shopping
Medical equipment steam sterilizers				
Jacket and Chamber Condensate Cooling Modification (water savings)	453,600-648,000	gal/year		Koeller and Riesenberger 2004
Estimated useful life	20	years		Koeller and Riesenberger 2004
Price of device	$2500	$/device		Koeller and Riesenberger 2004
Food steamers				
Water use boiler-based food steamers	78,840	gal/year		Food Service Technology Center Life-Cycle Cost Calculator
Water use connectionless food steamers	26,280	gal/year		Food Service Technology Center Life-Cycle Cost Calculator
Electricity usage of inefficient model	17,146	kWh/year		Food Service Technology Center Life-Cycle Cost Calculator
Electricity usage of efficient model	2,650	kWh/year		Food Service Technology Center Life-Cycle Cost Calculator
Estimated useful life	12	years		Karas et al. 2005
Price of boiler-based food steamers	$4,500-$5000	$/device	3-pan capacity	Katom.com
Price of connectionless food steamers	$4,800-$6,000	$/device	3-pan capacity	Katom.com

Ice machines				
Water use inefficient machine (air-cooled)	45,990	gal/year	Assuming an ice harvest rate of about 450 lbs/day	Food Service Technology Center Life-Cycle Cost Calculator
Water use efficient machine (air-cooled)	32,850	gal/year	Assuming an ice harvest rate of about 450 lbs/day	Food Service Technology Center Life-Cycle Cost Calculator
Electricity Usage of inefficient model	12,483	kWh/year		Food Service Technology Center Life-Cycle Cost Calculator
Electricity Usage of efficient model	10,184	kWh/year		Food Service Technology Center Life-Cycle Cost Calculator
Estimated useful life	10	years		Karas and Fisher 2007
Price of inefficient model	$2,300-$2,950	$/device		Google Shopping; Katom.com
Price of efficient model	$3,550-$4,230	$/device		Google Shopping; Katom.com
Waterless wok stoves				
Water savings	174,240	gal/year	Assuming 1 gal/min savings with 8 hrs runtime over 363 working days/year	CUWA 2015; David Zabrowski, Personal Communication
Estimated useful life	10	years		CUWA 2015
Price of conventional wok stoves	$2,450-$2,650	$/device	2-burner model	Caterequipment.com.au
Price of waterless wok stoves	$3,780-$4,000	$/device	2-burner model, including overseas shipping premium to be conservative	Caterequipment.com.au

Coin-operated clothes washers				
Top load washers water use	32.5	gal/load		Bamezai 2012
Front load washers water use	16	gal/load	18 lbs capacity washer	Bamezai 2012
Number of loads per day	6	loads/day		Bamezai 2012
Water heating			Assuming is the same as residential use	
Estimated useful life	10	years		Bamezai 2012
Price of inefficient clothes washers	$660-$1,080	$/device		Lowe's
Price of efficient clothes washers	$1,350-$1,740	$/device		Lowe's

Table 3.

Summary Data

Measures	Water Savings (gal/day)	Water Savings (gal/yr)	Electricity use avoided (kWh/yr)	Natural gas use avoided (therms/yr)	Comments
Indoor Residential Water Efficiency Measures					
Toilet	13.0	4,700			3.5 gpf to 1.28 gpf
Toilet	1.9	680			1.6 gpf to 1.28 gpf
Showerhead	4.0	1,400	150	7.3	2.5 gpf to 2.0 gpm
Clothes washer	19	7,100	500	24	
Dishwasher	1.1	410	52		
Indoor CII Water Efficiency Measures					
Toilet	14	5,200			3.5 gpf to 1.28 gpf
Toilet	2.1	750			1.6 gpf to 1.28 gpf
Urinal	7.5	2,700			Average to 0.125 gpf
Showerhead	12	4,300	470	22	2.5 to 2.0 gpf
Faucet aerators	4.3	1,600			2.2 to 1.0 gpm
Pre-rinse spray valve	19	7,000	600	26	
Medical equipment sterilizer modification	1,200-1,800	450,000-650,000			
Food steamer	140	53,000	14,000		
Ice machine	40	13,000	2,300		
Waterless Wok	480	170,000			
Coin operated clothes washer	100	36,000	2,600	120	

Note: Values are rounded to two significant figures. Energy savings depend on fuel source; electricity and natural gas savings are not additive. We use a percentage share for each fuel source in our cost savings calculations.

Outdoor Water Efficiency Measures

We examine the levelized cost of conserved water for outdoor water efficiency measures, including water brooms, rotary nozzles, and turf replacement. Unlike indoor water use, outdoor uses are typically consumptive, i.e., water is not available for immediate reuse due to evaporation, transpiration, or incorporation into plants. Therefore, we do not account for avoided wastewater treatment cost in our analysis. Additionally, we do not include avoided energy costs as outdoor water use is not heated.

For water brooms and rotary nozzles, we follow the same analytical approach as for indoor water efficiency measures, as described above. We offer additional explanations for the costs and cost savings of turf replacement below.

Lawn Conversion Costs

Under the landscape conversion measure, we consider the cost of removing and replacing turf with a water-efficient landscape as well as the landscape cost for new developments. Turf replacement costs are estimated at approximately $3 to $5 per square foot. This range is consistent with the SoCal WaterSmart program and the Gardens Green Group's field study in the Greater Los Angeles region (Pamela Berstler, personal communication, 2015). For a replacement of dead lawns or new installations, the costs are estimated at about $2 to $4 per square foot, which is the difference between the approximate cost of turf replacement and sod installations at about $1 per square foot (sod.promatcher.com). To simplify, our model is based on a lawn size of 1,000 square feet for the following cities: Fresno, Oakland, Sacramento, San Diego, and Ventura. Regional costs are adjusted using homewyse.com, an online reference for home maintenance and improvement projects. Actual costs may vary depending on design, labor costs, and material costs. Installations of larger plants, drip irrigation systems, and hardscapes such as stones, pavers, and concrete can increase the cost significantly.

Maintenance Cost Savings for Turf Replacement

Turf replacement provides additional savings from the reduction in fertilizer use and general maintenance. Native plants are adapted to the natural soil conditions and require very little or no fertilizer (Adamson et al. 2014). Low water-use landscapes also typically require less maintenance. We conservatively estimate that turf replacement reduces maintenance cost by 30% (Sovocool 2005). A case study in Santa Monica, however, shows that maintenance hours may be reduced by 68% (City of Santa Monica 2013).

Landscape Irrigation

Plant water needs depend, for example, on the type of crop, soil conditions, and a number of climatic factors (e.g., temperature, wind speed, and humidity). Due to changes in some of these parameters throughout the year, we use a landscape water requirement model to estimate irrigation needs at five locations throughout California to provide a range of water savings. This modeling method applies only to rotary nozzle installation and turf replacement.

We use a modified Simplified Landscape Irrigation Demand Estimation (SLIDE) approach to derive water savings from converting turf to low water-use landscapes. This method provides an appropriate balance between simplicity and conceptual soundness. Irrigation needs are calculated as follows:

$$\text{Irrigation Demand} = \sum_{i=1}^{12}\left(\text{ET}_{0,\text{i}} \times \text{PF} - \text{Pe}_\text{i}\right) \times \text{area} \times \left(\frac{1}{\text{DU} \times \text{IME}}\right) \times \text{conversion factor}$$

Where **irrigation demand** is in gallons per year

$\mathbf{ET_{0,i}}$ is the reference evapotranspiration for month I (values in inches per month)

PF is the plant factor

$\mathbf{Pe_i}$ is effective rainfall for month I (values in inches/ month)

DU is the distribution uniformity (unitless ratio)

IME is irrigation management efficiency

Area is the area of landscape in square feet

Conversion factor converts inches of rainfall per unit area to gallons of water

Evapotranspiration (ET) is an amount of water (in inches per month) that is lost to the atmosphere by the process of evaporation from soil and plant surfaces and transpiration from plant tissues. It can be simply understood as plants' water requirement. Reference ET or ET_0 is based on a reference crop, i.e., a well-watered grass that is completely shading the soil, and is provided by the 2015 Updated California Model Water Efficient Landscape Ordinance, or MWELO (DWR 2015). In order to determine a species-specific water requirement, ET_0 is adjusted by the plant factor (PF). We assume a plant factor of 0.8 for turf grass and 0.3 for low water-use plants. Effective rainfall (Pe) or water that is retained in the root zone and can be beneficially used by plants is subtracted from the plant's water needs. Pe does not include losses due to runoff, evaporation, and deep percolation.[2] We use average rainfall data from climate normal years (1981-2010) that are taken at selected weather stations in the study area.[3] Effective rainfall, the amount of rainfall that is beneficially used by plants, is roughly assumed to be 25% of annual rainfall (DWR 2010). It should be noted that rainfall at very low levels (e.g., less than 0.5 inches) is generally lost due to evaporation and rainfall at higher levels (e.g., more than 3.5 inches) may be lost due to runoff and deep percolation (Brouwer and Heibloem, 1986).

Irrigation efficiency (IE), or how well water is applied for beneficial use, is typically influenced by (1) how efficiently the irrigation system performs (e.g., drip vs. sprinkler); (2) how uniform the distribution of water is; and (3) how well crops respond to irrigation (Howell 2003). We estimate irrigation efficiency by drawing on the Model Water Efficient Landscape Ordinance (MWELO), in which irrigation efficiency is the product of distribution uniformity (DU) and irrigation management

[2] Deep percolation may be beneficially used to maintain salt balance.

[3] Weather data drawn from "Monthly Climate Normals (1981-2010)", NOAA NOWData: Oakland Museum, Fresno Area, Oxnard WSFO, San Diego Area, and Sacramento Area.

efficiency (IME). DU reflects how evenly water percolates the ground within an irrigation zone, while IME measures the efficiency of the irrigation system and how well water is being applied (e.g., high IME can be achieved with evapotranspiration controllers and other methods to adjust irrigation times to meet water needs). We assume the irrigation efficiency, or the product of the distribution uniformity and irrigation management efficiency, to be about 0.62, reflecting a spray and/or rotor sprinkler irrigation system. Lastly, a conversion factor of 0.623 is used to convert inches of water to gallons. It should be noted that actual volumes of applied water at the household level may vary by behavioral responses, potentially leading to under- or over-irrigation. A 2011 study of single family water use suggests that over-irrigation occurs in 44% of the lots studied (DeOreo et al. 2011). Households may also deficit irrigate, but overall, too much water is applied to landscapes. This excess volume averages 30,000 gallons on total irrigated lots (DeOreo et al. 2011).

The difference in irrigation needs for water-efficient and turf landscapes provides the basis for water savings estimates in each city under the model. Detailed analysis of the type of landscape, plants with a low water requirement, effective rainfall, irrigation behavior and other variables are needed to arrive at a better approximation of actual water savings.

Table 4.

Outdoor Water Efficiency Measures

	Value	Unit	Comments	Sources
Water Broom				
Water savings	137	gallons/day		CUWA 2015
Useful life	5	years		CUWA 2015
Price of a water broom	$100-$220	$/device		Google Shopping
Rotary nozzle				
Water savings	9.7%	of water use		Baum-Haley 2014
# of nozzles per 1,000 sq.ft. landscape	2	nozzles	13ft. radius for each nozzle	
Useful life	5	years		MWDOC 2013
Price of rotary nozzle	$6-$15	$/device		Rainbird.com
Price of fixed spray nozzle	$1	$/device		Rainbird.com
Lawn removal and replacement				
Cost of water-efficient landscape	$3-$5	$/sq.ft.	Approximate costs consistent with SoCal WaterSmart program turf replacement rebate and projects in Greater Los Angeles	
Cost of turf installation and materials	$1	$/sq.ft.	Approximate cost based on Fresno, Oakland, Sacramento, San Diego, and Ventura	sod.promatcher.com

Lifetime of lawn and water-efficient landscape	15	years	There is no easy way to determine the lifetime of a landscape, but we limit our scope to 15 years	
Plants replacement (plant and planting labor cost)	0.75	$/ft²/time	Estimated	Pamela Berstler, Green Gardens Group (3G), Personal communication
N-Fertilizer use (1,000 ft² area)	8.44-11.25 lbs/year	lbs/year	Calculated from Henry et al. 2002 and MacLachlan, W. (n.d.)	
Cost of N-fertilizer	$3.20	$/lb		Lowe's
Fertilizer application	3-4	times/year	Varies by location	Henry et al. 2002
Fertilizer cost savings	$27-36	$/year	Varies by location	
Lawn mowing cost				
Fresno	$ 43.99	$/visit		lawn-care.promatcher.com
Oakland	$ 51.26	$/visit		lawn-care.promatcher.com
Sacramento	$ 43.47	$/visit		lawn-care.promatcher.com
San Diego	$ 48.38	$/visit		lawn-care.promatcher.com
Ventura	$ 50.84	$/visit		lawn-care.promatcher.com
Frequency of mowing	28.56	times/year	Average values from using lawn mowers	California Air Resources Board 2012
Annual cost of lawn mowing	$1,260-$1,460	$/year	Varies by location	
Drought-tolerant landscape maintenance	30%	of turf maintenance		Sovocool 2005
Maintenance cost reduction	$400-$480	$/year	Varies by location	

Irrigation Water Needs				
Turf plant factor	0.8			DWR 2015
Non-turf plant factor	0.3			DWR 2015
Conversion factor	0.623		1 ft^3 of water = 7.48 gallons	DWR 2015
Irrigation efficiency (IE)	0.62		Assumed based on spray and/or rotor sprinkler irrigation system	
Average rainfall	Varies by city (Fresno, Oakland, Sacramento, San Diego, Ventura)		National Weather Service Forecast Office - Monthly Normals (1981-2010) Precipitation	
Effective rainfall	0.25			DWR 2010

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