Albuquerque Single-Family Water Use Efficiency and Retrofit Study

Prepared for:

Albuquerque Bernalillo County
Water Utility Authority

Prepared by:

Aquacraft
WATER ENGINEERING & MANAGEMENT

ALBUQUERQUE SINGLE-FAMILY WATER USE EFFICIENCY AND RETROFIT STUDY

Final Report

A Project Funded Through

The Drinking Water State Revolving Loan Fund

Green Project Reserve, and the

2009 American Recovery & Reinvestment Act

Prepared by

Aquacraft
WATER ENGINEERING & MANAGEMENT

For the

**Albuquerque Bernalillo County
Water Utility Authority**

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TABLE OF CONTENTS

GLOSSARY **14**

EXECUTIVE SUMMARY **27**

INTRODUCTION **32**

GOALS **34**

Household Post-Retrofit Water Use Information Provided 58

METHODOLOGY **35**

Study Group Selection 35

Comparison of Single-family Annual Water Use 36

Zip Code 45

Total 45

Sampling Procedure for Survey Group 45

Data Collection 47

Flow Trace Analysis 48

Calculating Landscape Water Requirements 49

Theoretical Irrigation Requirement 49

Estimation of Landscape Area 50

GIS Landscape Analysis 50

Ground Observations 51

Local Evapotranspiration Data 52

Calculating the Zone Coefficient K_z 53

Species Factor k_s 53

Density Factor k_d 54

Microclimate Factor k_{mc} 55

Landscape coefficient K_z 56

Effective Rainfall 56

Irrigation Efficiency 56

Calculating Theoretical Irrigation Requirement 57

RESULTS OF SURVEYS **58**

Response Rates to Surveys 59
Household Characteristics 59
Fixtures and Appliances 61
Attitudinal Comparisons 64
PRE-RETROFIT WATER USE 67
Annual Use of Logging Group 67
Indoor Use of Logging Group 68
Total Indoor Use 68
Disaggregated Indoor Use 71
Toilet Use 73
Clothes Washer Use 76
Shower Use 78
Leakage 80
Faucet Use 82
Per Capita Use Relationships 83
Household Efficiency Rates 85
Discussion of Indoor Use 87
Outdoor Use of Logging Group 88
Irrigated Areas versus Lot Sizes 89
Reference and Theoretical Irrigation Requirements 91
Application Ratios 92
Discussion of Outdoor Use and Combined Potential Savings 98
RETROFITS 99
In-Home Inspections 100
Home Selection 100
Description of Devices Used 101
Toilets 101
Showerheads 102
Clothes Washer 103
Faucets/Aerators 104
Irrigation Controllers 106

Master Valves 107
Final Retrofit List 107
Costs for Retrofit Program 108
POST-RETROFIT WATER USE 111
Total Indoor Use 112
Comparison of Disaggregated End Uses 113
Toilet Use 115
Clothes Washer Use 118
Shower Use 119
Leakage 122
Faucet Use 124
Per Capita Use Comparisons 127
Comparison of Household Efficiency Rates 128
Discussion of Water Savings 129
FACTORS THAT AFFECT WATER USE IN ALBUQUERQUE 132
Analysis of Water Waste Violations 132
Indoor Use Versus Number of Residents 136
Impact of Retrofits 137
Showers 137
Toilets 138
Paying for Water 138
Front Loading Clothes Washers 138
Presence of Youth in Home 138
Presence of a Stay-At-home During the Day 138
Swimming Pools and Spas 139
Garbage Disposals 139
Dish Washsers 139
Swamp Coolers 139
Attitudinal Responses (Q28) 139
SUMMARY AND CONCLUSIONS 140
APPENDIX A – SURVEY INSTRUMENT AND RESULTS 142

APPENDIX B – VERIFICATION LETTER 151

APPENDIX C – RETROFIT DEVICES BY HOUSEHOLD 153

APPENDIX D: SIDE-BY-SIDE COMPARISONS 175

List of Tables

Table 1: Table of unit conversion multipliers 25

Table 2: Annual water use statistics for Albuquerque single-family homes 36

Table 3: Comparison of water use among rebate groups 40

Table 4: Percent of population, rebates, and average lot size by Albuquerque zip codes 45

Table 5: Survey response rates 59

Table 6: Average number of persons per household 59

Table 7: Reported income data 60

Table 8: Age of home 60

Table 9: Number of bedrooms reported 61

Table 10: Number of toilets per home and toilet flush types 61

Table 11: Showers and showerhead types 61

Table 12: Clothes washers and clothes washer type 62

Table 13: Incidental kitchen and faucet fixtures 62

Table 14: Evaporative coolers, treatment and spas 63

Table 15: Whirlpool, greenhouses, multi-headed showers 64

Table 16: Irrigation, irrigation sources, and automatic sprinkler systems 64

Table 17: Attitudes about water conservation, showing percent of respondents saying they agree with the statement 65

Table 18: Financial attitudes for conservation and water rates, showing percent of respondents saying they agree with the statement 65

Table 19: Water monitoring and awareness, showing percent of respondents saying they agree with the statement (from Question 28) 66

Table 20: Annual use of Logging Group and population 68

Table 21: Indoor water use in Albuquerque compared to REUWS and EPA Retrofit data 69

Table 22: Toilet flush volume statistics in Albuquerque 73

Table 23: Clothes washer statistics in Albuquerque 77

Table 24: Shower statistics in Albuquerque 78

Table 25: Statistics on leakage in Albuquerque 80

Table 26: Faucet statistics in Albuquerque 82

Table 27: Normalized household use comparisons 84

Table 28: Efficiency criteria for penetration rate determination ... 85
Table 29: Outdoor water use in logging sample ... 88
Table 30: Lot size and irrigable area data for Albuquerque ... 89
Table 31: Net ET from Candelaria Weather Station in Albuquerque ... 90
Table 32: Reference and Theoretical Requirement data in Albuquerque ... 92
Table 33: Landscape and application ratios – Water Authority ... 94
Table 34: Excess application (kgal) ... 96
Table 35: Summary of total high efficiency devices and appliances installed ... 107
Table 36: Summary of Program Adjusted Costs ... 109
Table 37: Comparison of annual use ... 111
Table 38: Average indoor use comparison ... 112
Table 39: Toilet use comparison ... 116
Table 40: Comparison of single flush to dual flush toilets ... 117
Table 41: Clothes washer use data ... 118
Table 42: Comparison of shower use data ... 120
Table 43: Leakage statistics comparison ... 122
Table 44: Faucet use comparisons ... 125
Table 45: Daily per capita use relationships with retrofit homes ... 127
Table 46: Summary of Water Savings ... 130
Table 47: Potential Water Savings by Quartile ... 131
Table 48: Fine amounts versus number of violations received ... 133
Table 49: Summary of Water Waste Violations ... 134
Table 50: Number of citations by year ... 135
Table 51: Comparison of water use between violators and non-violators ... 136
Table 52: Impact of Rebates on Penetration of high efficiency devices ... 137
Table 53: Correlation factors for shower use ... 137
Table 54: Installed and retrofit devices ... 153
Table 55: High efficiency clothes washer performance survey ... 155
Table 56: High efficiency clothes washer satisfaction survey ... 158
Table 57: High efficiency toilets satisfaction survey ... 161
Table 58: High efficiency toilet performance survey ... 163
Table 59: Performance survey of showerhead ... 165

Table 60: Satisfaction survey of showerhead 166
Table 61: performance survey for the Delta H_2O faucet 167
Table 62: Satisfaction survey for the Delta H_2O faucet 168
Table 63: Change in water use behavior 170
Table 64: Comparisons of Pre and Post Retrofit Study Homes 175
Table 65: Tabulation of indoor water use, pre-retrofit, post-retrofit and the total savings. .. 179
Table 66: Tabulation of toilet use (in gallons), pre-retrofit, post-retrofit and the total savings. 180
Table 67: Tabulation of shower use (in gallons), pre-retrofit, post-retrofit and the total savings. 181
Table 68: Tabulation of clothes washer use (in gallons), pre-retrofit, post-retrofit and the total savings. 183
Table 69: Tabulation of faucet use (in gallons), pre-retrofit, post-retrofit and the total savings. 184
Table 70: Tabulation of leakage (in gallons), pre-retrofit, post-retrofit and the total savings. 185

List of Figures

Figure 1: Annual water use in Albuquerque study homes (kgal) 37

Figure 2: Percentage of indoor versus outdoor water use in Albuquerque 39

Figure 3: Comparison of annual, non-seasonal and seasonal water use 41

Figure 4: Percent of indoor rebates by zip code 42

Figure 5: Percent of outdoor rebates by zip code 43

Figure 6: Comparison of customers and rebates by zip code 44

Figure 7: Lot size as percent of average for zip codes 44

Figure 8: Meter Master 100 Flow Recorder attached to residential water meter 48

Figure 9: Percent of homes by daily consumption bin 70

Figure 10: Percent of total indoor water use by daily use bin 71

Figure 11: Indoor end-use pie chart for Albuquerque (% of total indoor use) 72

Figure 12: Comparison of household end-uses in Albuquerque Logging Group to REUWS 73

Figure 13: Average household toilet flush volume histogram 75

Figure 14: Toilet heterogeneity chart 76

Figure 15: Distribution of clothes washer volumes 77

Figure 16: Distribution of shower flow rates 79

Figure 17: Distribution of shower volumes 79

Figure 18: Percent of homes by leakage bin 81

Figure 19: Percent of total leak volume by bin 81

Figure 20: Distribution of household faucet use (gpd) 83

Figure 21: Indoor use versus the number of residents 84

Figure 22: Logging Group household compliance rates 86

Figure 23: Irrigated area versus lot size for Albuquerque 90

Figure 24: Actual versus theoretical applications for Albuquerque 93

Figure 25: Application ratio histogram 95

Figure 26: Distribution of excess use by percent of homes 97

Figure 27: Distribution of excess use by percent of volume 97

Figure 28: Projected water savings for Albuquerque single family accounts 99

Figure 29: Dual flush toilet (left) and single flush toilet 102

Figure 30: Handheld showerhead (left) and standard showerhead 103
Figure 31: Front loading clothes washer (left) and top loading clothes washer 104
Figure 32: Kitchen One Touch faucet (left) and kitchen flip lever 105
Figure 33: Lavatory flip lever aerator (left) and Push n Flow aerator...................................... 106
Figure 34: Comparison of pre and post daily indoor water use 113
Figure 35: Indoor end use pie chart for Post-Retrofit Group 114
Figure 36: Comparison of the Logging Group and the Post-Retrofit Group 115
Figure 37: Comparison of household flush volumes 117
Figure 38: Comparison of distributions of clothes washer volumes.. 119
Figure 39: Comparison of shower flow rate distributions... 121
Figure 40: Comparison of shower volumes 121
Figure 41: Comparison of shower durations.. 122
Figure 42: Percent of retrofit homes by leakage bin 123
Figure 43: Percent of total leakage by leakage bins.. 124
Figure 44: Comparisons of household daily faucet use... 125
Figure 45: Percent of faucet events by flow rate, post-retrofit 126
Figure 46: Percent of total faucet volumes by flow rate, post-retrofit 126
Figure 47: Comparison of per capita relationships 128
Figure 48: Comparison of household efficiency rates 129
Figure 49: Projected water savings from interior retrofits by quartile................................... 132
Figure 50: Comparison of indoor water use on a per-site basis.. 178

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Glossary

A	
Actual irrigation application	The volume of water estimated as outdoor or irrigation use. Calculated as total annual billed consumption minus best estimate of indoor use (kgal).
ABCUWA, Albuquerque Bernalillo County Water Utility Authority	Also referred to in the report as the Water Authority
AF, acre-foot	A volume of water that covers one acre of area to a depth of one foot, or 325,851 gallons of water. See conversion table below.
ANOVA, Analysis of variance	A mathematical process for separating the variability of a group of observations into assignable causes and setting up various significance tests[1].
Application ratio	The ratio of the actual irrigation application to the theoretical irrigation requirement; application ratios are key parameters in assessing irrigation use because they indicate at a glance whether a given site is over- or under-irrigating.

1 NIST *Engineering Statistics Handbook*

ARRA, American Reinvestment and Recovery Act	ARRA, passed by Congress in 2009, made $275 billion available for federal contracts, grants and loans with the goal of: • Creating new jobs and saving existing ones • Spurring economic activity and investing in long-term growth • Fostering unprecedented levels of accountability and transparency in government spending
AWC, average winter consumption	Average winter consumption is an estimate of indoor water use. It is typically calculated by averaging the water usage for the winter months of December, January, and February where it is assumed that all usage during that period of time is indoors. This value sometimes includes winter irrigation and may over-estimate true indoor use.

C

CCF or ccf	A measure of volume: one hundred cubic feet or 748 gallons. Also HCF. See conversions in Table **1** below.
Ccf/yr	Hundreds of cubit feet per year.
Confidence interval	For a given statistic calculated for a sample of observations (e.g. the mean), the confidence interval is a range of values around that statistic that are believed to contain, with a certain probability (e.g. 95%) the true value of that statistic (i.e. the population value). This report typically uses a confidence interval of 95%.

Current	The word "current" refers to the study period for this project, which was around 2009. All references to "current" demands or "current" data refer to the study period not the date of reading.
D	
Data logging	Collection of flow data from a water meter by use of a portable electronic device that records the number of magnetic pulses generated by the meter in a ten second interval.
DWR	Department of Water Resources
E	
ENERGY STAR	ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. The goals of the program are saving money and protecting the environment through energy efficient products and practices.
EPAct, The Energy Policy Act of 1992	An Act of Congress passed in 1992 with the goal of improving energy efficiency. It also included changes mandating 1.6 gpf toilets, and 2.5 gpm faucet aerators
EPA, Environmental Protection Agency	EPA leads the nation's environmental science, research, education and assessment efforts. The mission of the Environmental Protection Agency is to protect human health and the environment. Since 1970, EPA has been working for a cleaner, healthier environment for the American people.

EPA retrofit homes	A group of 96 homes selected in 1999 from existing single family homes in Seattle, East Bay MUD and Tampa. Each home was data logged and surveyed for baseline water use and then retrofit with high efficiency fixtures and appliance. Post-retrofit data were collected so that the impacts of the retrofits could be determined. These homes are used as benchmarks for high efficiency homes.
ET, evapo-transpiration	Evapotranspiration (ET), as used in this study, is a measurement of the water requirement of plants. According to California Irrigation Management Information Systems (CIMIS), evapotranspiration (ET) is the loss of water to the atmosphere by the combined processes of evaporation (from soil and plant surfaces) and transpiration (from plant tissues). It is an indicator of how much water your crops, lawn, garden, and trees need for healthy growth and productivity. See reference ET and net ET. The term ETo refers to specific reference crops such as cool season turf (for urban use).
Excess use, excess irrigation, excess irrigation use	Excess irrigation occurs when the application ratio is greater than one. Excess irrigation, as used in this report, is the difference between the actual volume of water applied to the landscape and the theoretical irrigation requirement, with all values less than one set to zero. This represents the sum of all excess use without netting out the deficit use.
Explanatory variable	A variable used as part of a regression analysis as a parameter to attempt to predict or model another variable. One or more explanatory variables are commonly used in an attempt to predict the value of a single dependent or objective variable. For example household water use was an important dependent variable in this study, which was related to changes in several explanatory variables such as persons per home, size of home, cost of water, presence of high efficiency fixtures and appliances.

F	
Flapper leak	In trace analysis, a periodic leak, often with a flow rate similar to a toilet's flow rate at a given site.
Flow trace data analysis	The process of disaggregating end uses of water for a given meter from a record of 10 second interval flow data.
G	
gal	Gallon, a measure of volume. See conversion table below.
GIS analysis	Geographic Information System. GIS is a system of capturing, storing, analyzing and presenting geographic data.
gpd	gallons per day
gpcd	gallons per capita per day
gpf	gallons per flush
gph	gallons per hour
gphd	gallons per household per day
gpl	gallons per load
gpm	gallons per minute
gpsf	gallons per square foot
H	
HCF, hundred cubic feet	A measure of volume: one hundred cubic feet or 748 gallons. Also CCF. See conversion table.

HET, high efficiency toilet	When used in capital letters the term refers to toilets designed to flush at 1.28 gpf or less.
Histogram	A graphical way of showing the distribution of a sample or population in which the X axis normally shows a group of ranges (or bins) of values, and the Y axis shows the frequency of the data points tha fall into the bin. By dividing the number of points in each bin by the total number of datapoints the relative frequency, expressed as a percent, can be shown. The cumulative frequency can also be shown, which is the sum of the relative frequencies at or below a given bin.
I	
Irrigated area	Portion of a lot's area that is irrigated. Does not include house footprint, hardscape, etc. Irrigated area is a critical parameter for irrigation analysis. There was a very strong correlation between irrigated area and total lot size demonstrated by the data.
K	
K_c (crop co-efficient)	The crop coefficient is used with ETo to estimate the evapotranspiration rates of a plant (often turf) relative to a reference crop (usually cool-season grass).
Keycode	A unique alpha-numeric code used to identify each study home. The first two digits of the code represent the year in which the home was data-logged, the letter the type of meter (i.e. single-family, commercial, irrigation) and the last three digits are unique to the study home.
Kgal	Unit of volume equal to 1,000 gallons. See conversion table below.

L

L, liter	A measure of volume, equal to 0.264 gallons.
LA, landscape area	Portion of a lot's area that is irrigated. Does not include house footprint, hardscape, etc. Irrigated area is a critical parameter for irrigation analysis. There was a very strong correlation between irrigated area and total lot size demonstrated by the data.
Landscape aerial analyses	Utilizing aerial imagery and GIS analysis to identify landscaping features such as likely plant types and corresponding area.
Landscape coefficient	The weighted average of crop coefficient for landscape (Kc). Represents the aggregate landscape for a given site. Lower values imply more xeric landscape, while higher values higher water-using landscape.
Landscape ratio	This is the ratio of the theoretical irrigation requirement to the reference requirement based on ET_o
"leaks"	Whenever the term "leak" is enclosed in quotes this is intended to remind the reader that these events may include uses that are not actually leaks, but which give the appearance of leaks based on flow rates, durations, and timing patterns.

Leaks and continuous events	Events that are identified as leaks during flow trace analysis. These fall into two categories: small and random events that do not appear to be faucet use due to there small volume, timing and often repetitious nature, and long continuous events that appear to be due to broken valves or leaking toilets. Note that some continuous uses may be due to devices like reverse osmosis systems that are being operated on a continuous basis.
Logging Group	The group of 209 homes selected from the population of single family homes to match the water use characteristics of the population. Used as the benchmark for disaggregated water use in the population of single family homes.
Low flow	Describes toilets, faucets and showerheads that meet the 1992 EPAct requirements
Logging	Practice of installing data loggers on customer water meters. Same as data logging.
Lot size	Lot size is a measure of the total area attributed to a given study site. Often found from parcel data.
lpf	liters per flush
M	
Mean	A hypothetical estimate of the typical value. For a set of n numbers, add the numbers in the set and divide the sum by n.
Median	The middle number in an ordered set of observations. Less influenced by outliers than the mean.

MEF, modified energy factor	Measures the energy consumption of the total laundry cycle (washing and drying). It indicates how many cubic feet of laundry can be washed and dried with one kWh of electricity; the higher the number, the greater the efficiency.
MG	Unit of volume equal to 1,000,000 gallons. See conversion table below.
Mgd	millions of gallons per day
MG	A unit of volume: million gallons per year.
N	
N or n	number of observations or sample members.
NEPA	National Environmental Policy Act
Net ET	Equal to Reference ET less effective precipitation. Net ET is a key parameter in analysis and prediction of water use.
NOAA, National Oceanic and Atmospheric Administration	An agency within the Department of Commerce. Focus is on oceans and atmosphere, including weather. Maintains weather stations throughout the United States.
P	
Post-Retrofit Group	Refers to the group of 29 homes selected from the top quartile of the Logging Group *after* receiving the retrofits.
Pre-Retrofit Group	Refers to the group of 29 homes selected from the top quartile of the Logging Group *prior to* receiving the retrofits.

R	
R^2 , coefficient of determination	The proportion of variance in one variable explained by a second variable. It is the square of the correlation coefficient, which is a measure of the strength of association or relationship between two variables.
Reference evapo-transpiration (ET_o)	ET_o measures the moisture lost from a reference crop (normally cool season grass for urban purposes (inches)) and the soil due to temperature, solar radiation, wind speed, and relative humidity. Precipitation is not included in the measurement of ET_o although it does affect several of the parameters in the ET equation such as solar radiation and relative humidity.
Reference requirement	The volume of irrigation water required for a landscape planted exclusively with cool season turf and a 100% efficient irrigation system.
Regression	A method for fitting a curve (not necessarily a straight line) through a set of points using some goodness-of-fit criterion.
REUWS homes, Residential End Uses of Water Study homes	This refers to the sample of approximately 1,200 single family homes chosen randomly from the service areas of 12 water providers in 1997. These are considered representative of existing single family from the1996 time period, prior to widespread implementation of the 1992 Energy Policy Act requirements.
S	
Sf	A measure of area, square feet.

Single-family home	For purposes of this study, a single-family home refers to a single meter feeding single dwelling unit. Generally detached, but may be attached as in the case of duplexes, triplexes etc, but each unit must be individually metered. Apartments are not included.
SPSS-Statistical Package for the Social Sciences	An analytical software package for statistical analysis used to evaluate the Water Authority's single family residential billing data.
Standard deviation	An estimate of the average variability (spread) of a set of data measured in the same units of measurement as the original data. It is the square root of the sum of squares divided by the number of values on which the sum of squares is based minus one[2].
Standard error	This is the standard deviation of the sampling distribution of a statistic. For a given statistic (e.g. the mean) it tells how much variability there is in this statistic across samples from the same population. Large values, therefore, indicate that a statistic from a given sample may not be an accurate reflection of the population from which the sample came.
Standard flush toilets	As used in this report the term "standard flush toilet" refers to toilets meeting the 1992 ULF criteria of 1.6 gpf.
T	
TDS	Total dissolved solids

2 Field, Andy. 2009. *Discovering Statistics Using SPSS, Third Edition.* SAGE Publications Inc. Thousand Oaks, CA.

Theoretical Irrigation Requirement (TIR)	The volume of water (kgal) needed to meet the calculate requirements of the landscape for a given lot. It is a function of irrigated area, net ET, landscape ratio, irrigation efficiency.
U	
UCCE	University of California Cooperative Extension
ULF toilets	Ultra low flow toilets. In 1992 ULF toilets represented the best efficiency toilets available. Currently, HET or high efficiency toilets are the best available devices. When used in this report the term ULF refers to toilets designed to flush at 1.6 gpf.
W	
WF, water factor	The number of gallons or water needed to wash each cubic foot of laundry. The lower the number the more efficient the machine.
WaterSense	An EPA Partnership Program created to aid water conservation through labeling of water efficient products, services and buildings.

Table 1: Table of unit conversion multipliers

UNITS	GAL	CF	CCF	KGAL	AF	MG
GAL	1	0.134	1.34 x 10-3	1.0 x 10-3	3.07 x 10-6	1.0 x 10-6
CF	7.48	1	0.01	7.48 x 10-3	2.30 x 10-5	7.48 x 10-6
CCF	748	100	1	0.748	2.30 x 10-3	7.48 x 10-4
KGAL	1000	133.7	1.337	1	3.07 x 10-3	1.00 x 10-3
AF	325,851	43,560	435.6	325.852	1	0.33
MG	1,000,000	13,370	133.7	1000	3.07	1

Note: multiply number of units in column 1 by the number in the body of the table to convert to units shown in row 1, for example: 10 MG x 3.07 = 30.7 AF.

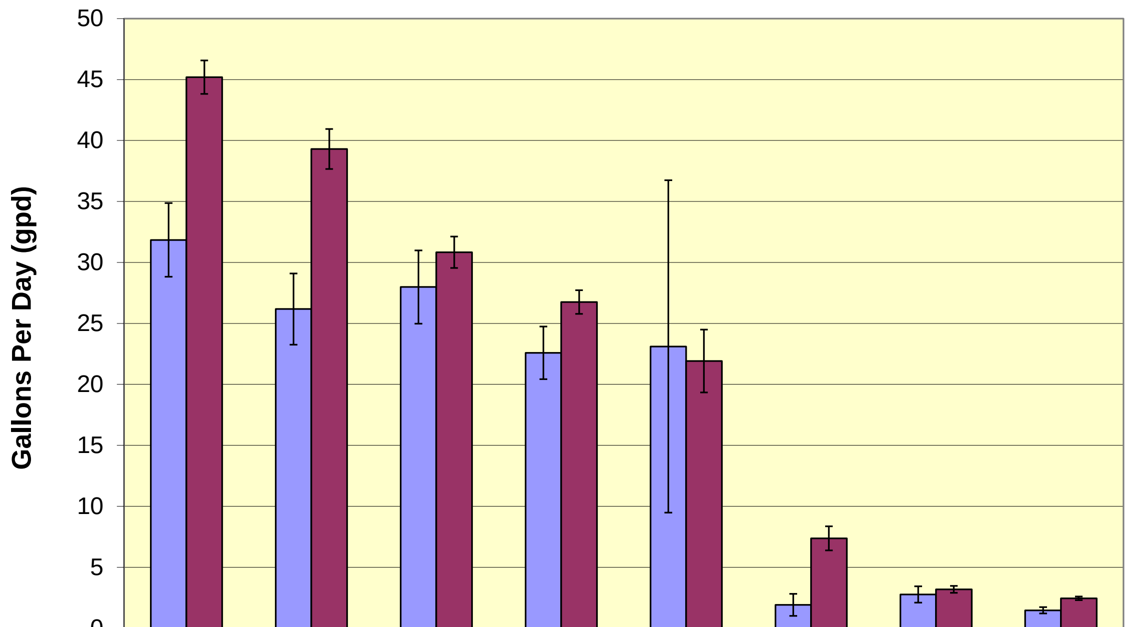
Executive Summary

The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) has established a goal of reducing its overall water use to 150 gpcd by 2014. Given the fact that nearly half of the water use in the system is devoted to single family residential uses the Authority determined that it would be beneficial to conduct a detailed investigation of the current water use patterns of its single family customers, and to determine the potential water savings available wihin the group. Towards this end the Authority contracted with Aquacraft, Inc. to conduct a baseline study of single famiy water use conducted on a representative sample of customers. A second component of the study was a retrofit study on a group of 29 homes chosen from the baseline group. This retrofit group had their fixtures and appliances upgraded to high efficiency devices and their water use was measured afterwards to determine the potential savings from the program. While both indoor and outdoor water use were studied it turned out the there was more potential for indoor savings in the group, since very few of the homes were found to be over-irrigating during the baseline logging period. The lack of significant over-irrigation meant that any outdoor intervention would have required re-landscaping the yards with lower water use plants, or less irrigated area. Both of these options were beyond the types of actions included in the work plan. Consequently, the study focused primarily on the impacts of indoor retrofits for reducing single family water use.

Using billing data from 2009 it was determined that the average annual water use of the single family customers was 94 kgal per year, and that two thirds of this water (65 kgal) was non-seasonal use and one third was seasonal. Non-seasonal use is sometimes used as a proxy for indoor use, but frequently contains both indoor use and “winter” irrigation. By data-logging the sample of homes it was possible to determine that the actual indoor use averaged 138 gphd, or 50 kgal per year

The data logging group was selected from customers who returned a in –home survey. The logging group was checked to ensure its water use matched that of the survey group. The results of the surveys are provided after the Methodology section of the report.

The water use data from the logging group was disaggregated into end uses. Figure ES 1 shows a breakdown of the baseline water use in the homes, and compares this to the results from the 1999 Residential End Uses of Water Study group, which is considered a benchmark for existing homes dating from the study period. As shown in the figure, the baseline use in Albuquerque was substantially lower than the 1999 baseline from the REUWS.



	Toilet	Clotheswasher	Shower	Faucet	Leak	Other	Bathtub	Dishwasher
Logging Group	31.84	26.18	27.99	22.58	23.11	1.92	2.77	1.47
REUWS	45.2	39.3	30.8	26.7	21.9	7.4	3.2	2.4

Figure ES 1: Disaggregated indoor water use in Albuquerque compared to REUWS sample

As part of the retrofit, all of the toilets, clothes washers, faucets and showerheads in the retrofit group were replaced with high efficiency devices, which basically equaled the Water Sense specifications with the addition of tier 3 type clothes washers. All faucets were equipped with quick shut off devices in hopes that this would reduce the faucet run times. The homes were re-logged after the retrofits and their water use was compared pre and post retrofit. The average daily use by end-uses comparison is provided in Figure ES 2. This shows that the retrofits results in major reductions toilet use, clothes washer use and leaks. The other categories remained fairly constant. We believe that the large reduction in leaks was an artifact of the toilet replacement.

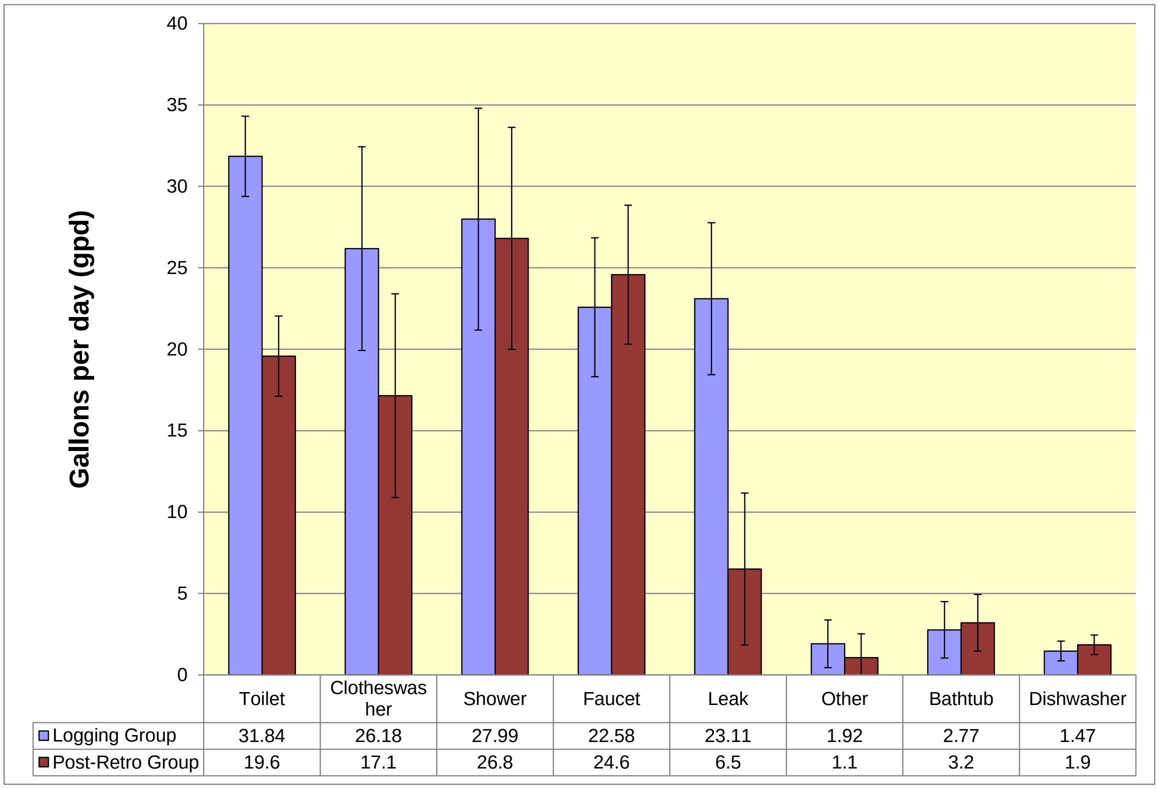


Figure ES 2: Comparison of pre and post retrofit water use

The indoor per-capita use relationships from the pre and post samples were determined and then compared to similar relationships obtained from standard homes and other high efficiency homes which Aquacraft has studied. These show that the post retrofit homes in Albuquerque are among the most efficient in any of the groups, which can be seen by examining Figure ES 3. This figure also shows that as the homes become more efficient the household water use is less dependent on the number of persons in the home.

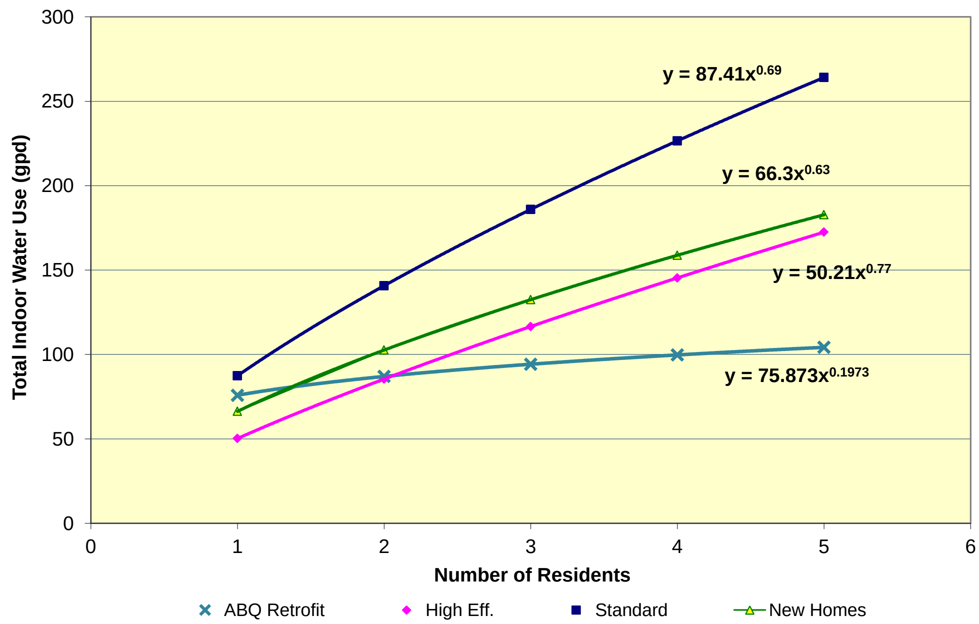
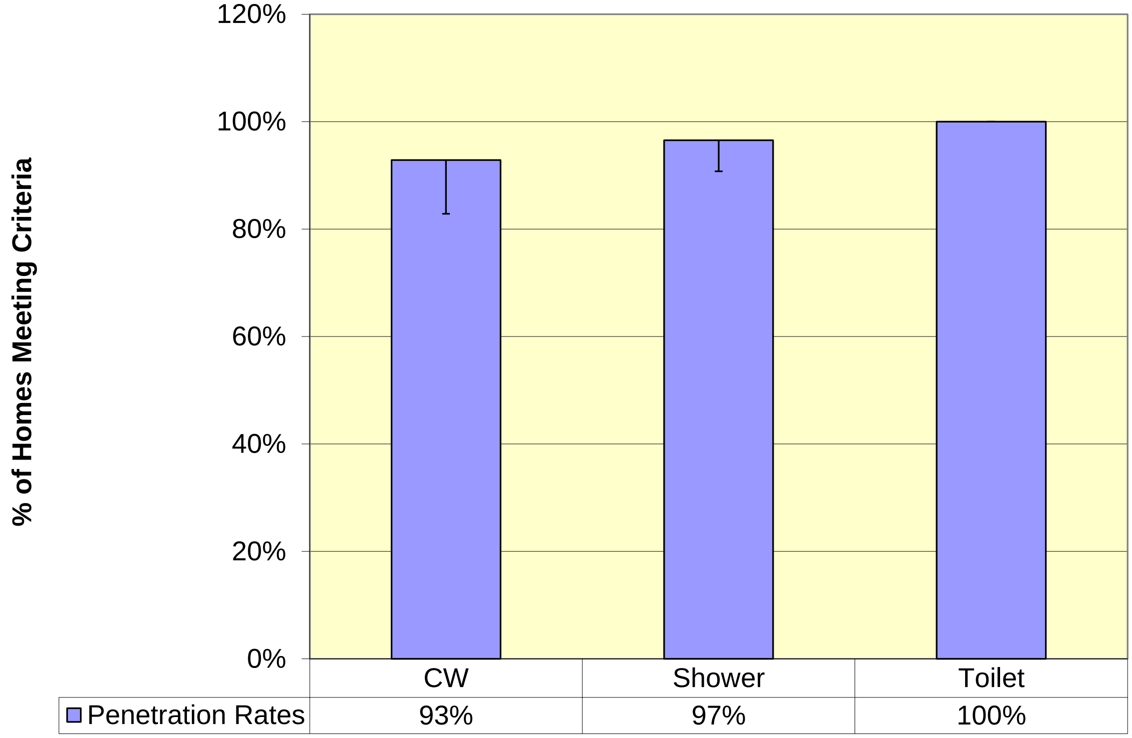


Figure ES 3: Comparison of per capita use relationships in Albuqerque post retrofit homes

In order to gage the level of efficiency of the homes three criteria were used for the study. Homes with average clothes washer load volumes of 30 gallons or less, shower flow rates of 2.5 gpm or less, and aveage toilet flush volumes of 2.0 gpf or less were deemed to be high efficiency homes for each category of use. After the retrofits more than 90% of the homes met the study criteria for high efficiency in clothes washers, showers and toilets. Prior to the retrofits the percentages for the three categories were 46%, 81% and 35% respectively.



The study projected water savings based on the assumption that an average indoor use of 101 gphd was achievable if all homes are equipped with similar fixtures and appliances used for this study. Table ES 1 shows that the total expected water savings amount to 8724 AF/Yr. This volume of savings is equivalent to approximately 20% of the total single family water use recorded in 2009. The table also shows that these savings are not evenly distributed across the population of single family home. The homes in the bottom 2 quartiles, which are already at or below the 101 gphd level would not be expected to generate significant amount of savings, while the homes in the upper two quartiles are expected to be the source of the majority of the savings. The top quartile would be expected to generate 80% of the entire savings. In reality, many of the homes in the lower quartiles would still probably be able to save water since they are most likely low consumers because they have fewer occupants. In these cases, while the savings would be smaller, they would still be present. On the other hand, some of the homes in the top quartile may not be able to drop down to the 101 gphd level, but overall, the goal of 8700 af of savings appears to represent a good target for the system conservation program for indoor uses in single family customers.

Quartile	Weighted	Target	No. HH's	Potential Savings	Percent of Total

	Average Baseline Use	**Use**		**for Quartile**		
	(gphd)	(gphd)	N	(gd)	(AF/Yr)	%
1	49	101	35,799	0	0	0
2	97	101	35,799	0	0	0
3	145	101	35,799	1,562,349	1,750	20
4	275	101	35,799	6,225,624	6,974	80
Total			**143,194**	**7,787,973**	**8,724**	**100**

Table ES 1: Projected water savings from single family sector

All of the savings shown in Table ES 1 are from indoor uses, and the bulk of them will come from reductions in clothes washers, toilets, showers and leaks. The reduction in leakage is an important component of the effort , and appears to be related to reduced leakage resulting from the toilet replacement, since no other direct leak repairs were undertaken as part of the retrofit program. The last two sections of the report discuss the factors that were found to relate to indoor water use in single family customers, and provide some overall conclusions. The most important conclusion, however, is that that there is a significant potential for saving potable water, perhaps up to 20% of the total single family use in 2009, from simply upgrading the key indoor fixtures and applainces, and by taking steps to reduce leakage.

Introduction

The Albuquerque Bernalillo County Water Utility Authority (Water Authority) was awarded funding through the American Recovery and Reinvestment Act (ARRA) of 2009 Green Project Reserve through a Drinking Water Revolving Loan for contract work on the Albuquerque Single-family Water Use Efficiency and Retrofit Study. The goal of this study was to obtain a detailed analysis on the indoor and outdoor water use patterns of a random sample of single-family homes in the Water Authority's service area. This information is intended to show how much water was used in the homes for each of the major domestic end-uses. In addition, several types of efficiency data were obtained for indoor use such as the average gallons per flush for toilets, the flow rates for showers and faucets, and the gallons per load for clothes washers.

Outdoor water use for the study homes was characterized with respect to the total annual outdoor use, the actual application rate to the landscape in inches, and the theoretical irrigation requirement for the home based on the irrigated area by plant type, local net ET and reasonable irrigation efficiencies based on the type of irrigation system. The ratio of the actual application to the theoretical requirement (the application ratio) was used as one key efficiency parameter. Homes with ratios greater than one were presumed to be applying more than the theoretical requirement, and homes with ratios less than one were presumed to be applying less than the theoretical requirement.

In addition to providing a benchmark for water use in the community, this information will be useful for evaluating and quantifying water savings from plumbing codes, retrofits, and irrigation efficiency measures, and focus areas for future water savings. The information collected in this study is intended to provide the Water Authority with service area data for evaluating the efficiency of current single-family home usage, and for determining the maximum potential for residential water use efficiency.

There has been a considerable amount of study done on single-family water use both in the form of baseline studies, such as the REUWS[3] from 1999, which characterized water use in random samples of single-family customers and intervention studies such as the EPA Retrofit Study[4] from 2003, which demonstrated potential efficiency levels from use of best available technologies. These studies show a range of efficiency levels for single- family homes. The Albuquerque Single-Family Water Efficiency and Retrofit Analysis will build upon the previous REUWS and other retrofit studies to provide a much needed focus on New Mexico water demands.

It is hoped that the residential demand information will greatly assist Water Authority's long-range water planning efforts. Conservation is a major component in ensuring the availability of adequate

3 Aquacraft, 1999. Residential End Uses of Water, Denver.

4 Aquacraft, 2003. Combined Retrofit Report for Seattle, EBMUD and Tampa.

supplies of safe drinking water for the Water Authority. This study and its findings of current single-family residences will assist not only the Water Authority but other communities throughout the State of New Mexico.

Goals

The goal of this study is to provide the Water Authority with a complete water use analysis from a random sample of homes from their service area and to determine the percentage of homes that meet study specific criteria for high efficiency fixtures and appliances. End use consumption data will be collected from each home in the sample in order to develop a complete water use.

Information from surveys and other sources will be used to develop relationships between the presence of high efficiency fixtures and appliances, the size of the home, the irrigated area in turf and non-turf, the type of irrigation controller used, the presence of rain shut off devices, local ET, participation in Water Authority sponsored conservation programs, etc.

Post-retrofit end use consumption data will be collected to demonstrate the actual savings possible when best available technologies are employed in the homes.

The data collected from the Albuquerque Single-Family Residential Water Efficiency Study will be used to address these and other questions:

- What percentage of the potential water conservation in the single-family category has already been captured, and what percentage is still available?
- What are the most important end-uses of water that require additional conservation programs and incentives?
- How effective have past regional and local conservation programs been?
- What is the potential water savings possible if single family homes are equipped with water efficient fixtures and appliances?

The answer to these questions will have important statewide implications about the design of future water management programs and allocation of resources. Developing a realistic assessment of the potential for water conservation in Albuquerque’s largest urban demand sector - single family homes - is the single most important objective of this study.

Methodology

Study Group Selection

A total of 3000 homes were sampled from the Water Authority's billing database for survey mailing, and annual/seasonal water use analysis. A copy of the survey is attached as Appendix A. In order to examine the impact of the Authority rebate program on water use, one half of the survey group (1500 customers) was selected at random from customers who did not receive any rebates from the Water Authority, and the other half was selected from customers who received either an indoor or an outdoor rebate, or both. From returned surveys, which included a consent to participate, a random sample of 240 homes plus 30 alternates was selected for data logging in order to obtain the necessary detailed end-use information. Alternates were selected to ensure a large enough sample in the event that a customer moved or needed to withdraw from the study. These 270 customers received a verification letter, a copy of which can be found in Appendix B, prior to equipment installation. Data logging produced valid data for 209 of these 240, with routine equipment failure and insufficient use during the logging period causing most of the losses.

Several sources of data were used to characterize the water use patterns and efficiency levels of the single-family water customers in the Water Authority's service area. This report provides a summary of the statistics and end-use results for these customers. Results for both indoor and outdoor use are presented here.

Prior to drawing a sample of single-family homes for inclusion into the survey group an analysis of water use was conducted from the Water Authority's billing data in order to determine if there were significant differences in water use among rebate groups. Beginning in 1995 the Water Authority has distributed a large number of rebates to single-family customers. The single-family customers were broken down into five groups based on their rebate status:

1. All single-family customers,
2. Customers who have not received any rebates,
3. Customers who have received at least one indoor rebate (mainly toilets or clothes washers),

4. Customer who have received at least one outdoor rebate (for re-landscaping or irrigation controllers), and
5. Customers who have received at least one indoor and one outdoor rebate.

The 2009 single-family billing data provided by the Water Authority were analyzed using the Statistical Package for the Social Sciences (SPSS) program and the following results were obtained.

Comparison of Single-family Annual Water Use

There were a total of 151,978 single-family accounts in the Water Authority water billing database in 2009. The average annual water use by these customers was 94.8 kgal and their median annual water use was 79.3 kgal. Table 2 provides the summary statistics for 2009 annual water use for Albuquerque single-family homes obtained from the billing data. Figure 1 shows the annual water usage from the sample of 3000 homes that received surveys. Survey respondents were used to select the logging homes in Albuquerque.

Table 2: Annual water use statistics for Albuquerque single-family homes

	Water Use (2009)
Total Use	14,407,500 kgal 44,215 AF
No Accounts	151,978
Average	94.8 kgal
Median	79.3 kgal

Figure 1 shows the distribution of annual water use for the single-family homes selected to receive surveys. As with all of the histograms in this report, the values on the X-axis represent the top of the data bin, so the chart is read in the following manner: Three percent of the homes used 25 kgal annually or less while 71% of the homes used 125 kgal or less annually.

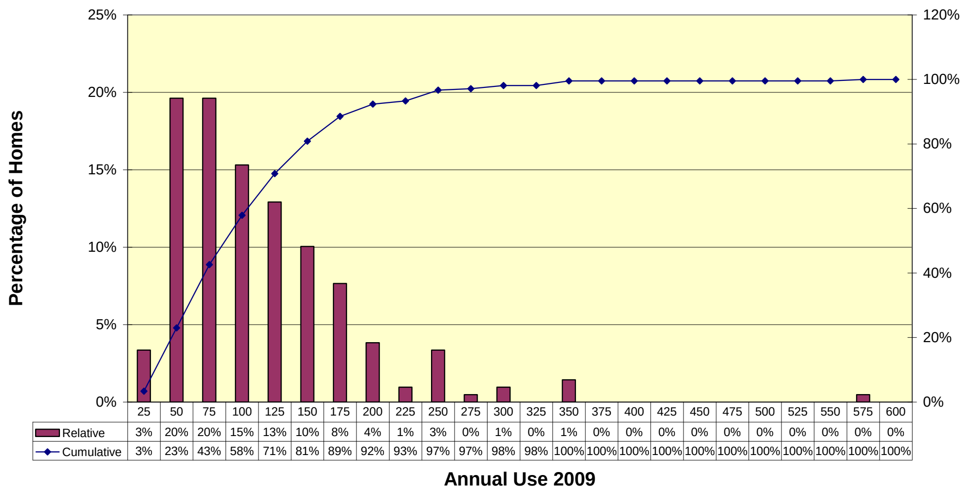


Figure 1: Annual water use in Albuquerque study homes (kgal)

Table 3 shows the data for the five rebate groups. The entire database contained 151,978 records, as shown in the table, but when accounts with incomplete data were screened out there were 143,190 used for sample selection. These were used as the total of single-family accounts for the analysis. The billing data were first converted from units of hundreds of cubic feet (ccf) to units of thousands of gallons (kgal)[5]. Annual water use included all months of 2009; non-seasonal use was calculated as the average of billed usage from December through March multiplied by 12. Seasonal use was calculated as the annual use minus the non-seasonal use. Non-seasonal use is used as an estimate for indoor use (since there is little winter irrigation in Albuquerque), and seasonal use is used as an estimate for outdoor use.

As shown in Table 3 the annual water use for the survey group in 2009 averaged 94.8 kgal per household per year. This use is low when compared to the average annual water use of 146 kgal in the 12 study sites from the REUWS homes (Aquacraft, 1999). In the recently drafted California Single-family Water Use Study[6] the average annual single-family use in ten large California water

5 1 ccf = 748 gallons = 0.748 kgal

6 DeOreo, W.B., et al, 2009. California Single Family Home Water Use Efficiency Study

agencies was 132 kgal per household. Assuming 2.5 persons per household, the Albuquerque annual use averaged 104 gpcd in 2009, which closely matches data from 2005 reported by Western Resources Advocates[7]. The use for the REUWS group was 172 gpcd. The annual use for the customers who received rebates tended to be higher than that for the general population or for customers who have not received rebates. As explained below, this is due to the higher outdoor (seasonal) water use in the rebate group, since the indoor use is similar for all of the rebate groups.

The indoor (non-seasonal) use for all of the single-family homes averaged 63.0 (84.1 ccf) kgal per year in 2009 which accounts for 67% of their annual water use. Looking at the data for the rebate groups there were no major differences in indoor water use between most of the rebate groups. The only group that had noticeably lower indoor water use was the group that had received an outdoor rebate. It is not clear why an outdoor rebate would reduce indoor use; it may show that conservation of outdoor water correlates to indoor conservation as well. The weighted average of the two other rebate groups was 63.2 kgal per year (84.7 ccf). This is equivalent to 173 gallons per household per day (gphd). The indoor use for the REUWS groups was 169 gphd, and for the California Single-family Home Study it was 175 gphd. The indoor use for the EPA Retrofit group was 110 gphd (Aquacraft, 2003). Figure 3 shows the comparison of annual, non-seasonal, and seasonal water use by rebate group.

Outdoor water use averaged 31.7 kgal per household per year which represented 33% of the annual water use. There are some differences in seasonal (outdoor) use among the groups, which affect both seasonal and annual water use. While the overall average outdoor use is low, the outdoor use for all three rebate groups is *larger* than the outdoor use for either the entire population or for homes that have never received any rebates. Homes that have received indoor, outdoor or both types of rebates have significantly higher outdoor water use than homes that have not received any rebates. This may be counter-intuitive, but is probably due to the fact that the homes that received rebates were among the higher income and had larger lots that normally consume more water than the general population. It is doubtful that the rebates led to increased outdoor water use. The breakdown of indoor and outdoor use is shown in Figure 2.

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7 WRA, 2006. Water in the Urban Southwest, An Updated Analysis of Water Use in Albuquerque, Las Vegas Valley and Tucson.

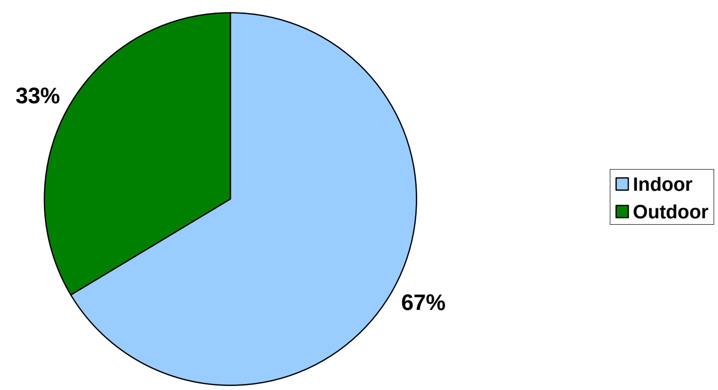


Figure 2: Percentage of indoor versus outdoor water use in Albuquerque single family customers

An analysis of the breakdown of rebates by zip code shows that the distribution of rebates is not the same as the distribution of customers. Figure 4 and Figure 5 show maps of Albuquerque with the percent of indoor and outdoor rebates within each zip code shown geographically. Figure 6 compares the percent of the customers in each zip code to the percentage of outdoor rebates in each. The occurrence of rebates is not proportional to the percentage of customers in each zip code. For example, as shown in Table 4, zip code 87111 contains 12% of the customers, but it accounts for 19% of the indoor rebates and 18% of the outdoor rebates. At the other end of the spectrum, zip code 87121 contains 11% of the accounts, but accounts for only 3% of indoor rebates and 1% of outdoor rebates. The reason for the difference is mostly likely that zip code 87111 is an older area and zip code 87121 is more recently developed with water efficient fixtures and landscaping as required by code.

There is clearly a tendency for large outdoor rebates to occur in zip codes with large lots. The zip code, billing system account and parcel feature classes were used in ArcMap to determine the average single-family lot size by zip code. The results are listed in the last column of Table 4. The overall average lot size for all single-family accounts was 5,358 square feet. The zip codes in this table are listed in decreasing order of the percentages of outdoor rebates each contains. Zip code 87111 contained the most outdoor rebates and 87121 contained the fewest. In order to show the relationship between lot size and outdoor rebates the ratio of the average lot size in each zip code to the average for the group as a whole is shown in Figure 7. This figure shows that the top seven zip codes, which account for nearly 79% of all outdoor rebates, all have larger than average lot sizes.

Table 3: Comparison of water use among rebate groups

				Annual Use (kgal) 2009			Non-Seasonal Use (kgal) 2009			Seasonal Use (kgal) 2009		
Group	Rebate Group	Number (1995-2009)	Percent of Pop	Mean	95% CI	Median	Mean	95% CI	Median	Mean	95% CI	Median
1	All Customers	151,978	100%	94.8		79.3	63.0		53.9	31.7		18.0
2	No Rebate	108,935	72%	90.9	0.4	76.3	63.0	0.3	53.9	27.9	0.2	14.2
3	Indoor Only	37,920	25%	104.6	0.7	87.5	63.3	0.4	53.9	41.3	0.5	27.7
4	Outdoor Only	2,153	1%	100.3	3.5	83.8	61.4	1.8	51.6	38.9	2.4	26.2
5	Both	2,970	2%	107.5	3.2	91.3	62.5	2.4	53.9	44.9	1.6	34.8

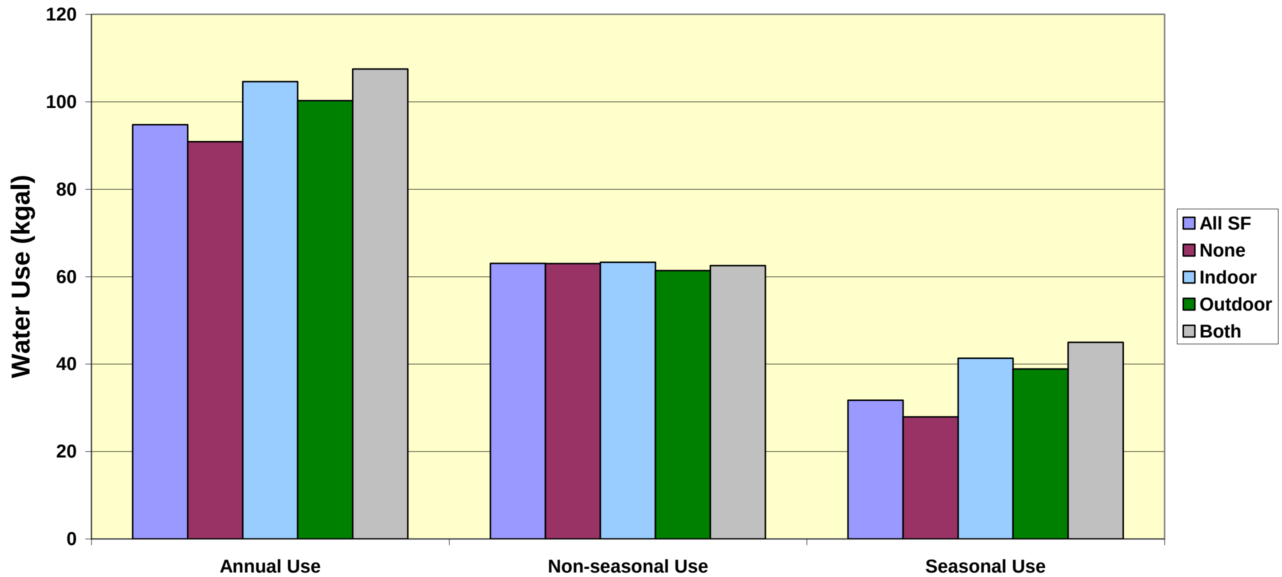


Figure 3: Comparison of annual, non-seasonal and seasonal water use in rebated and non-rebated groups

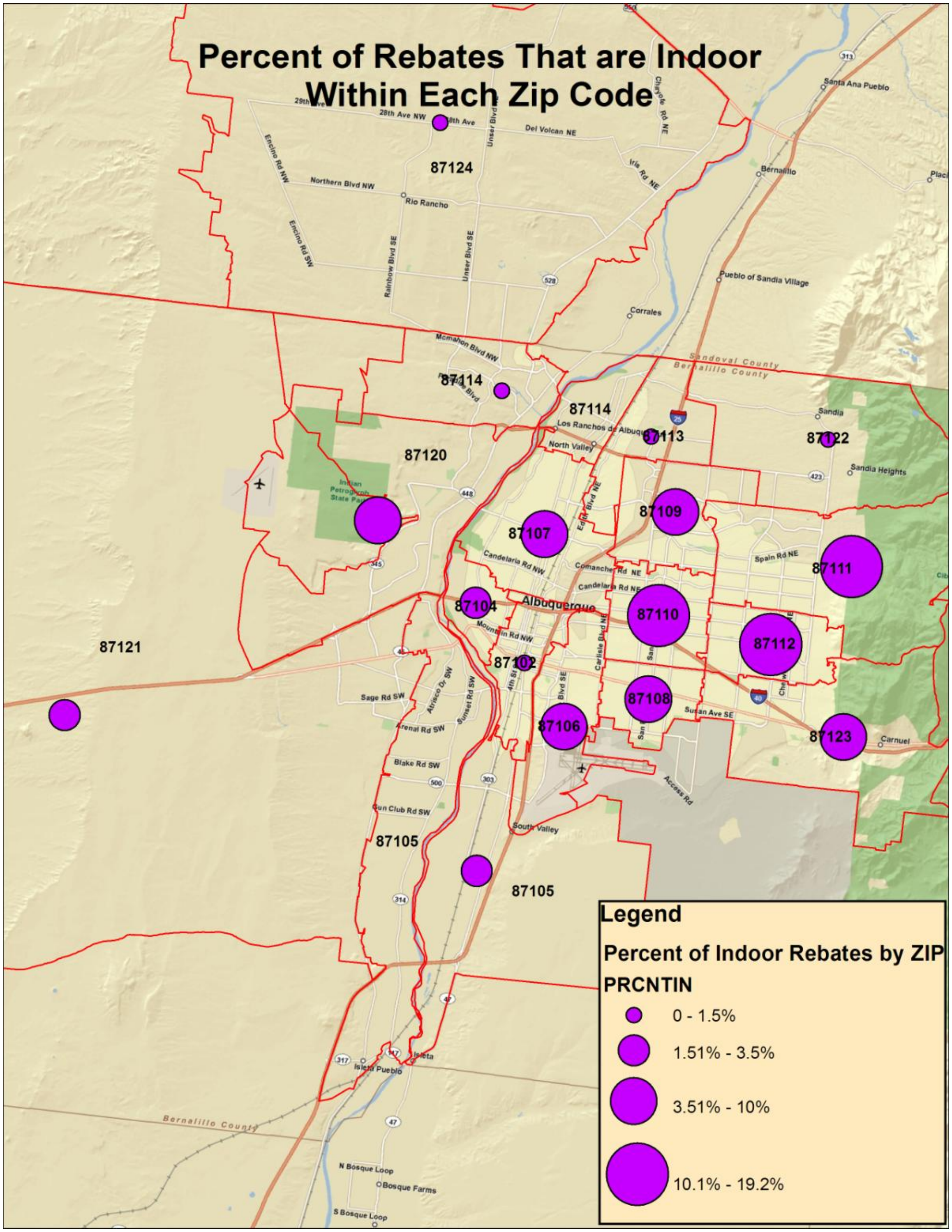


Figure 4: Percent of indoor rebates by zip code

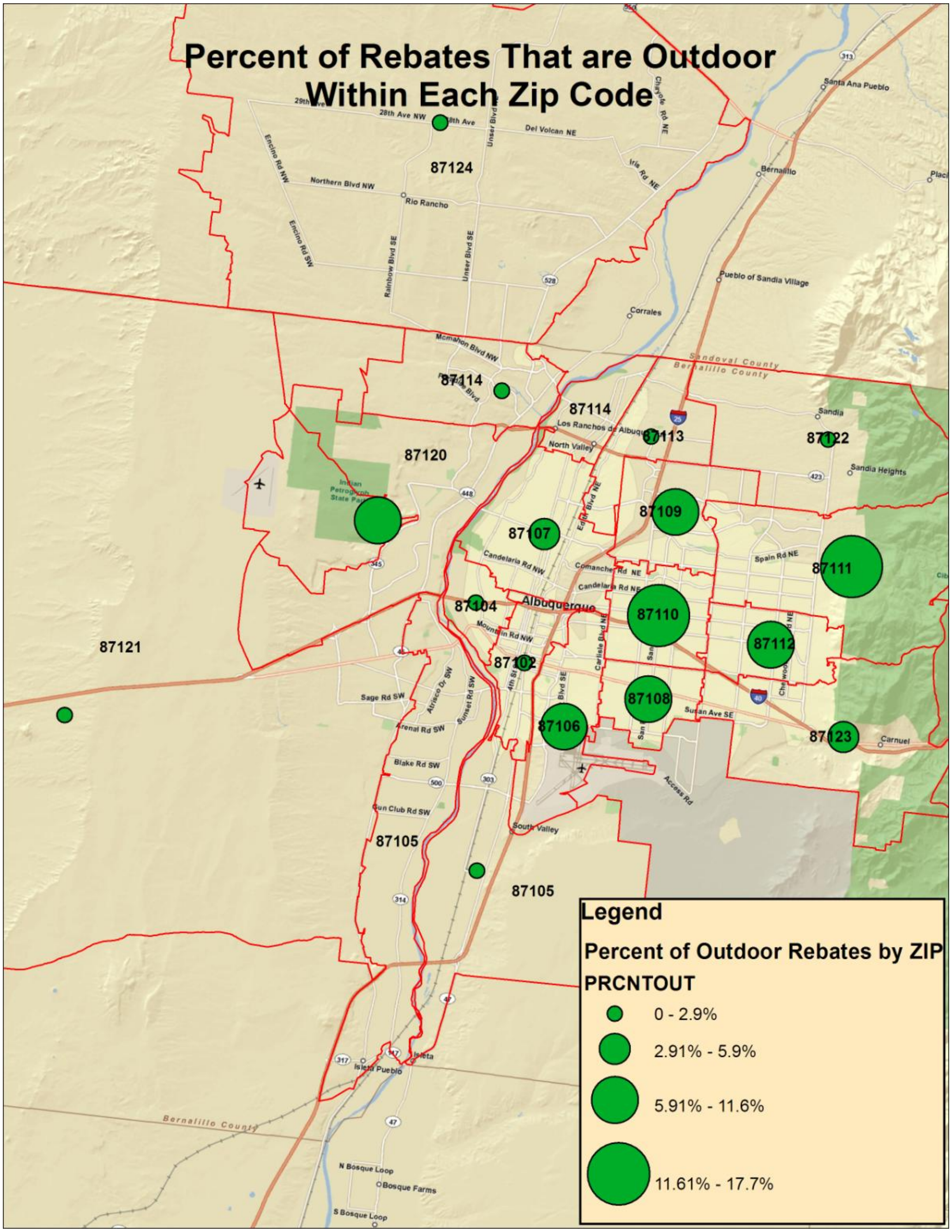


Figure 5: Percent of outdoor rebates by zip code

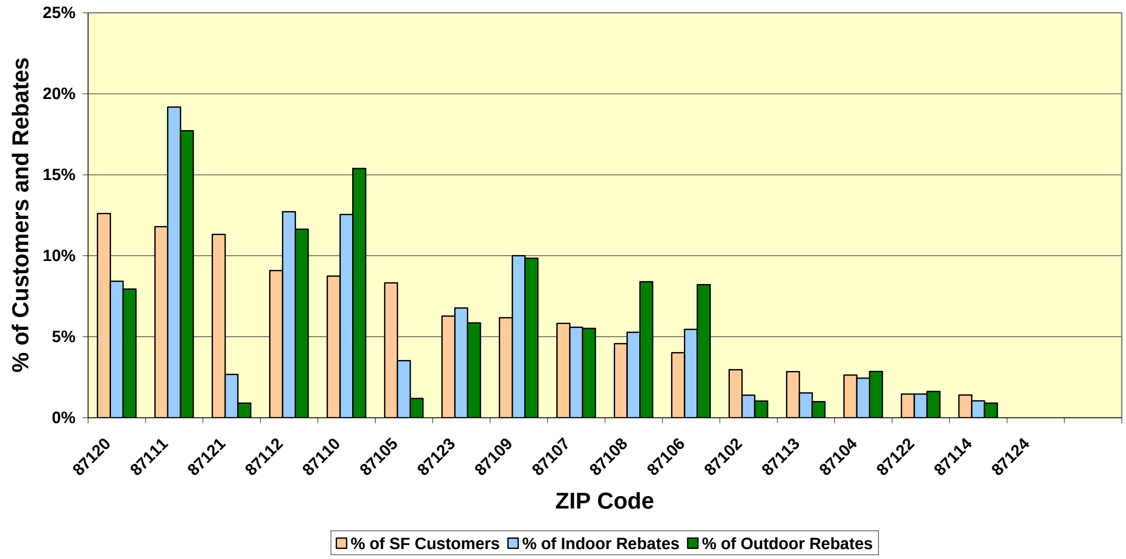


Figure 6: Comparison of customers and rebates by zip code

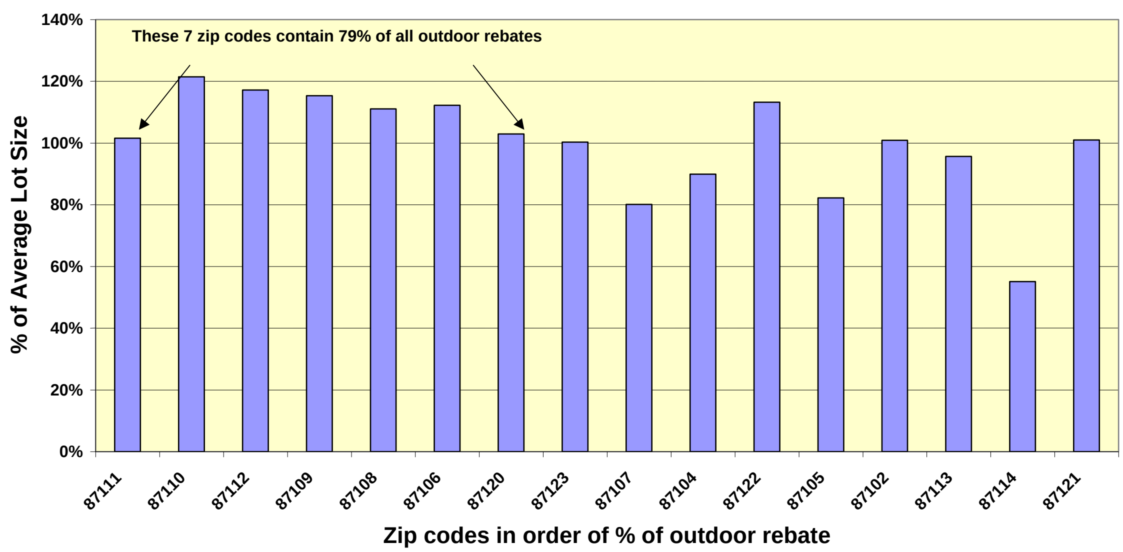


Figure 7: Lot size as percent of average for zip codes having largest to smallest percent of outdoor rebates

Table 4: Percent of population, rebates, and average lot size by Albuquerque zip codes

Zip Code	% of Single Family Customers	% of Indoor Rebates	% of Outdoor Rebates	Average Lot Size (sf)	Average Annual Use (kgal)	Average Non-seasonal Use (kgal)	Average Seasonal Use (kgal)
87111	11.79%	19.17%	17.72%	5441	113.5	66.5	47.0
87110	8.75%	12.54%	15.39%	6508	100.7	61.5	39.1
87112	9.08%	12.71%	11.63%	6278	93.7	61.4	32.3
87109	6.17%	10.01%	9.84%	6180	105.8	64.4	41.4
87108	4.57%	5.27%	8.40%	5951	88.7	57.5	31.2
87106	4.01%	5.45%	8.22%	6012	93.6	58.4	35.3
87120	12.60%	8.42%	7.95%	5514	94.2	64.7	29.5
87123	6.27%	6.77%	5.85%	5375	97.9	63.1	34.9
87107	5.82%	5.58%	5.51%	4292	100.0	63.9	36.2
87104	2.64%	2.44%	2.85%	4817	89.1	57.2	31.9
87122	1.46%	1.46%	1.63%	6067	120.3	73.7	46.6
87105	8.32%	3.52%	1.19%	4404	85.4	66.2	19.2
87102	2.96%	1.39%	1.03%	5406	71.9	54.8	17.1
87113	2.84%	1.53%	0.99%	5125	82.1	57.7	24.3
87114	1.40%	1.04%	0.90%	2952	97.3	65.9	31.5
87121	11.32%	2.67%	0.90%	5410	78.2	63.4	14.7
Total	**100%**	**100%**	**100%**	**5358**	**94.8**	**63.0**	**31.7**

Sampling Procedure for Survey Group

Based on these analyses it is clear that the indoor (non-seasonal) use is not related to the rebate group of customers. The only rebate group that showed a difference in non-seasonal use was the outdoor rebate group. This may be due to the fact that people who have gone to the effort of reducing their outdoor use may have also made efforts to manage their indoor use as well. The other four rebate groups have statistically identical indoor use.

Outdoor (seasonal) use does appear to be related to whether the property has had a rebate, but the relationship is the opposite of what one would expect. Customers who have had any rebate at all tend to have *higher* seasonal use, and this difference is statistically significant. Aquacraft does not believe that this means that the rebates have increased water use, but only that customers who have had rebates tend to be among the higher water using groups prior to obtaining their rebates. The zip code analysis shows that most of the rebates have taken place in zip codes in central or northeast Albuquerque, a quadrant understood to contain more affluent neighborhoods. Data from the GIS data show that the zip codes with the majority of outdoor rebates all have larger than average lot sizes.

Saying that the rebate groups do not have lower water use than the non-rebate groups does not simply mean that the rebates have not reduced water use. It means that as of 2009 the accounts that have had rebates use the same average amount for indoor uses as the general population and slightly larger amounts for outdoor use. These same customers may have been using significantly more water prior to the rebates. The way to measure the impacts of the rebates more precisely would be to compare the water use of the customers who received them before and after the rebates occurred. This pre-post analysis would show the actual impact on water use of the rebates on the customers who received them. A single year analysis, as performed in this report with 2009 data, simply shows how the rebate groups compare to the population and the non-rebate groups at a point in time.

Given the fact that the water use of the customers in the various rebate groups was so similar, and the Water Authority has an interest in obtaining more information on how the rebates have affected their customers water use the following procedure were adopted after consultation with the Authority for selection of the survey group.

- Select half of the survey group (1500 customers) at random from the 108,935 customers who have not received any rebates. This will represent 1.4% of these customers.
- Select the other half from the 43,043 customers who have received either an indoor or an outdoor rebate, or both. This will represent 3.5% of these customers.

- Since the indoor use appears consistent for the entire group of customers we should be able to select the logging sample from the larger water users in order to get information on the outdoor uses, and still get representative information on all of the indoor users. So, we suggest that the logging sample be chosen from the all respondents, irrespective of their rebate status such that the average annual water use of the Logging Group was 105 - 108 kgal per year.
- As shown in Figure 2, two-thirds of the water use in the single-family customers is for indoor purposes. This means that the indoor water use is a relatively more important category for conserving water in Albuquerque.
- The average annual ET in Albuquerque is 38.1 inches (WRA, 2006). This is equivalent to 24 gallons of water per square foot of turf. Even for the largest irrigation group, which has an average of 45 kgal per year of outdoor water use, this implies an irrigated area of only 1875 sf. This, along with the low overall percentage of outdoor water use, shows that Albuquerque has been successful in its effort to limit the amount and intensity of outdoor water use in the service area. While there will certainly be potential savings identified in outdoor use, these will probably come from a small number of customers who, for whatever reason, are over-irrigating or irrigating a large number of high water using plants.

Data Collection

The objective of this study was to collect a large set of data from single-family home customers with sufficient details to allow for disaggregation into end-uses. To provide the necessary resolution, 10 second flow trace data were collected from the main water meters serving study homes. Meter Master Flow Recorders (Model 100) were used for this purpose. Figure 8 shows a typical installation onto a residential water meter.

Figure 8: Meter Master 100 Flow Recorder attached to residential water meter

These data loggers recorded the flow of water through the water meters for a two week period following the responses from the household survey. Another two weeks of flow trace data were collected once the retrofits were complete.

Flow Trace Analysis

The purpose of flow trace analysis is to obtain precise information about water use patterns: where, when, and how much water is used by a variety of devices including toilets, showers, baths, faucets, clothes washers, dishwashers, hand-held and automatic irrigation systems, evaporative coolers, home water treatment systems, leaks, and more. The collected data from small meters are precise enough that individual water use events such as a toilet flush or a clothes washer cycle or miscellaneous tap use can be isolated, identified and then quantified. This technique makes it possible to disaggregate most of the water use in a residential home and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts.

The flow trace methodology is based on the fact that there is consistency in the flow trace patterns of most water uses. For example, a specific toilet will generally flush with the same volume and flow rate day in and day out. A specific dishwasher exhibits the same series of flow patterns every time it is run. The same is true for clothes washers, showers, irrigation systems, etc. By recording flow data at 10-second intervals, a rate determined by Aquacraft to optimize accuracy and logger memory, the resulting flow trace is accurate enough to quantify and categorize almost all individual water uses in each study home.

Trace Wizard is a software package developed by Aquacraft Inc., specifically for the purpose of analyzing flow trace data. Trace Wizard provides the analyst with powerful signal processing tools and a library of flow trace patterns for recognizing a variety of residential fixtures. Any consistent flow pattern can be isolated, quantified, and categorized using Trace Wizard including leaks, evaporative coolers, humidifiers, and swimming pools. Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event.

Calculating Landscape Water Requirements

The water needed to maintain a healthy residential landscape is determined by several factors that can be estimated with a reasonable degree of accuracy through measurement or calculation. The factors that can often be measured are the area of the landscape and the local climate data. Those that are calculated are the efficiency of the irrigation system, the average water needs of the plants (as a result of evapotranspiration), the microclimate, and the density of the plants.

Theoretical Irrigation Requirement

In an agricultural setting the goal of irrigation is to maximize plant growth and crop yield. In an urban environment, however, the goal is merely to apply sufficient water to maintain a healthy and attractive landscape. The amount of water needed to maintain a reasonable landscape in an urban environment, as opposed to maximizing plant growth, is classified as the theoretical irrigation requirement (TIR), and has be measured in this study as a volume of water in gallons. Typically each landscape is composed of several smaller sub-areas, each with its own characteristics of plant type, microclimate, and density. The efficiency of the irrigation system also factors into the calculation of

TIR. Once the water requirements of each sub-area have been calculated it is a simple matter to determine the water requirement of the landscape.

Because the actual irrigation applications were based on annaal billed use minus the best estimate of indoor use, the actual use was not available for each irrigation zone. Consequently, it was not possible to determine the actual water use or application ratios for each plant type or irrigation zone. Both the actual application and and application ratios were based on annual water use for the entire landscape. In order to provide actual use on a zone basis would have required significantly more data logging and analysis of the irrigation sysytems (to link individual zones with the flow traces) than was anticipated by the work plan.

The landscape characteristics were determined through a combination of aerial photo analysis and ground observations. The zone coefficient was determined based on the plant type present in each zone, as well as the microclimate and density of that zone. As with area, this was determined using both aerial photos and ground observations. The allowed irrigation efficiencies were based on the type of irrigation system normally used to irrigate the plant material in the zones: rotors, sprayers, or drip with the assumption that the system was well designed and in good condition.

Estimation of Landscape Area

Estimation of the landscape area of these residential sites was performed using the high resolution aerial images made available from the City of Albuquerque. The detail provided by these images generally made it possible to differentiate between turf areas, shrub borders, deciduous and coniferous trees, low-water use planting, and non-irrigated areas. Conclusions about the areas were verified with ground observations. One of the areas requiring most care was in determining whether areas were irrigated xeriscapes or non-irrigated native land.

GIS Landscape Analysis

The geo-spatial analysis used to identify and disaggregate landscape areas was performed in ArcView. Six-inch resolution ortho-imagery tiles, corresponding to the logged homes, were provided by Water Authority. These imagery data were collected in 2008 between late March and mid-April. The ortho-imagery was projected in ArcMap to ensure accurate calculations of landscape polygon areas.

To avoid double counting of digitized areas that overlap (i.e. tree canopy covering a portion of turf area) ArcMap geoprocessing tools were used to erase portions of turf, and polygons that either had shrub or tree overhang. The result of this step was that tree canopy and shrub areas were subtracted from the underlying areas.

The fact that the orthophotos were taken in early spring made it possible to see through the deciduous tree canopies, but made it more difficult to distinguish plants from mulches and bare soils in some of the images. The general approach was to use the imagery to digitize the boundaries of landscape areas as well as the house footprint, pools and fountains, and the total lot boundary based on the parcel layer provided by the Water Authority. After these GIS techniques were completed field staff visited study sites and performed on-the-ground comparisons to the digitized landscapes.

The net result of GIS analysis was a table showing the individual landscape polygons, their areas, and selected plant type with respect to water demand. The analyzed aerial images were then used during ground observations in order to verify the GIS analysis.

Ground Observations

While aerial analysis provides considerable detail and was the first step in landscape analysis, a site visit provides additional detail about the landscape. The landscape may have changed during the time that has elapsed since the aerial photographs were taken and the time of the data-logging; turf areas may have been converted to low water-use planting; unplanted areas may be seasonal gardens.

Ground observation was used to confirm (or update) the findings from the aerial images. When possible, the field technician walked the property with the homeowner; any changes made to the analyzed aerial photograph were made while consulting with the homeowner. When the homeowner was unavailable, the analyzed aerial photograph was left at the home along with detailed instructions for editing the aerial photograph. Changes made by the homeowner or during ground observations were applied to the original aerial photograph and parcel database to ensure the most accurate analysis possible.

The analyses of the landscape area are important for the study because the theoretical irrigation requirements, described above, rely heavily on the area assigned to each plant type. If the overall irrigated area for each plant type is not correct, then the theoretical irrigation requirements will either over or under-estimate the real values. A frequent issue in these analyses is whether or not to assign a given polygon a plant type that results in an irrigation allocation for that polygon. For example, if a lot contained a large parcel of native vegetation, a decision needed to be made as to whether this be classified as non-irrigated land or low water use land? For our analysis the principal was the following: land that was not formally landscaped, and was not in a position where it could extract water from the irrigated landscape by root invasion, was classified as non-irrigated.

Local Evapotranspiration Data

The amount of water lost from the landscape is the result of evaporation from the soil surface and the plants as well as the water that transpires through the plant surfaces. The water lost due to evapotranspiration (ET) is dependent on local weather conditions including temperature, wind speed, relative humidity, and solar radiation. These are all factors that affect ET and have local variation. The local reference evapotranspiration (ET_o)is normally determined from specialized weather stations that collect data needed for an energy balance type of equation such as the Penman or Penman/Monteith. These data were collected at the Candelaria weather station in Albuquerque and provide both historic and current ET_o.

While originally developed for use in agriculture, evapotranspiration (ET) data now has much broader applications and is important in determining the water needs – in the form of precipitation and irrigation – of a residential landscape. The amount of irrigation required to maintain healthy plants may be more or less than that required by a reference crop. The water requirement of a reference crop has been measured in laboratory and field studies and is referred to as ET_o. Commonly the reference crop used to calculate the water requirements of the landscape is cool season turf grass. The reference crop is grown in full sun, maintained at a height between 4 and 7 inches, is dense enough to shade the soil surface, and is provided with sufficient water to optimize growth and prevent stress. ET_o is calculated for each 24-hour period and is usually reported daily for current ET_o values and provided monthly for historic ET_o values.

Calculating the Zone Coefficient K_z

Not all areas of the landscape have the same water needs as that of the reference crop. That difference is reflected by zone coefficient K_z and is determined by three factors in the landscape which are:

- Species – k_s
- Density – k_d
- Microclimate – k_{mc}

The zone coefficient, K_Z, is calculated using the following formula:

$$K_Z = k_s \times k_d \times k_{mc}$$

Species Factor k_s

Not all plants lose water at that same rate nor do they require the same amount of water throughout the year. Many drought tolerant species have developed mechanisms to reduce water loss through evaporation and transpiration and may thrive with little or no supplemental irrigation. However these same mechanisms may result in a significant consumption of water if that water is made available through irrigation.

> "Soil water availability plays a major role in controlling the rate of water loss from plants (ET rate). Many plants will lose water at a maximum rate as long as it is available. For example, some desert species have been found to maintain ET rates equivalent to temperate zone species when water is available. When soil moisture levels decrease, however, ET rates in desert species decline rapidly."[8]

Some species, such as cool season turf grasses, may require considerable supplemental irrigation to sustain them during dry summer conditions. Fruits trees may have high water needs during fruit

8 UCCE & DWR, 2000. A Guide to Estimating Irrigation Water Needs of Landscape Planting in California, The Landscape Coefficient Method & WUCOLS III.

production but require minimal irrigation during the winter time when the tree is bare. These varying water requirements, known as the species factor, k_s have been divided into five categories that range from non-irrigated to high.

The species factor represents the fraction of reference evapotranspiration that needs to be applied to the landscape in order to "maintain acceptable appearance, health and reasonable growth for the species," according to the UCCE and DWR report. The species factor is often given as a range (e.g. 0.1 – 0.3) but for the purposes of this study k_s will be assigned a single number within the range that can then be used to calculate the landscape coefficient for the entire landscape. One of these five species factors will be assigned to each of the landscape areas:

The five categories are:

- Non-irrigated – 0.0 (not landscaped, not irrigated, not in close proximity to irrigated parcels)
- Very low – 0.1 (requires supplemental irrigation only during extended dry periods)
- Low – 0.3 (requires infrequent supplemental irrigation)
- Moderate – 0.6 (requires less irrigation than cool season turf and more irrigation than low water-use plants)
- High – 0.8 (irrigation needs similar to cool season turf)

Although k_s is not known for all plants and can vary throughout the growing season, it was still possible to assign a species factor to areas of the landscape in one of the five categories with a reasonable degree of accuracy. During GIS analysis areas of the landscape were assigned to a category based on an estimate of water needs and represented by k_s. To the extent possible these categories were confirmed with ground observations at the site. When there were mixed plantings within a landscape area the species factor was assigned based on the water needs of the plant that predominates in that area.

Density Factor k_d

Evapotranspiration loss from a given area is dependent not only on the plant species but on the density of the planting and is represented by the density factor k_d. For example, an area that is completely covered with turf has a much higher density factor than does an area with immature plants interspersed throughout the landscape. The density factor may vary with time of year as well.

Deciduous trees that have a higher density factor when they are leafed out in the summer than in the winter.

There are three levels of density factor that are applied to the landscape and as with the species factor these levels are given as a range (e.g. 0.5 – 0.9 for low density) but for the purposes of this study the density will be assigned a single number within the range that will then be used in the calculation of the landscape coefficient for the entire landscape.

- Very low – 0.25 (very little plantings)
- Low density – 0.5 (immature or sparsely planted)
- Average density – 1.0 (typically one plant type e.g. turf)
- High density – 1.3 (plantings with a mixture of planting types)

The data available for k_d in the landscape is fairly limited and based on agriculture studies (largely orchards). Nevertheless the density factor has been applied successfully to residential landscapes. The density factor is applied to the GIS landscape map and to the extent possible confirmed with ground observations at the site.

Microclimate Factor k_{mc}

Landscapers and gardeners know that different areas of the landscape can be subject to different weather conditions. A plant that grows happily on the east side of the landscape in the shade of the house may succumb when exposed to winds or the baking sun on the west side of the house. Variations in humidity, wind, light intensity, and temperature impact the amount of water needed in the landscape and create what are commonly referred to as microclimates or k_{mc}. The microclimate factor k_{mc} is assigned a value of:

- Low – 0.5 – 0.9 (shaded for part of the day with little wind or no wind)
- Average – 1.0 (equivalent to reference evapotranspiration conditions)
- High – 1.1 – 1.3 (increased evaporative losses due to reflected or absorbed heat or windy conditions)

Although the microclimate factor is relatively easy to determine on-site it is not possible to determine from GIS mapping or during a brief site visit. Because it is assumed that multiple microclimates exist on each property the landscaped areas will be assigned an average k_{mc} of 1.0.

Landscape coefficient K_z

Once the k_s and k_d have been assigned to each landscape area (k_{mc} is assumed to be 1.0) it is a simple matter of multiplying them together to calculate the landscape coefficient for each zone K_z .

Effective Rainfall

Rainfall is not part of the ET_o formula but must be considered when determining the irrigation requirement of the landscape. Plants in the non-irrigated areas of the landscape would not survive without some form of precipitation, usually in the form of rainfall. However not all of the rainfall is available to the plants. There are many factors that can affect the extent to which precipitation is available to the plants such as:

- Runoff from hardscape
- Compacted soil surface
- Saturated soil
- Over-hanging tree canopy
- Non-homogeneous soil type

In other words, only some percentage of the rainfall is actually available for the plants to use. The portion of the total rainfall that is effective in reducing plant water requirements is subtracted from gross ET_o to derive net ET_o, which represents the amount of water needed to be supplied from irrigation to meet the full water requirements of the reference crop.

Irrigation Efficiency

Often landscapes are over-irrigated as a result of inefficiencies in the irrigation system. Broken heads, mismatched precipitation rates, poor spacing, and improper hydrozoning may result in using more water than is necessary to maintain the landscape. However, even a well-designed and well maintained irrigation system is not 100% efficient and this must be considered in establishing the TIR. Automatic irrigation of residential landscapes usually consists of one of three types of irrigation:

- Drip irrigation (efficiency – 90%)

- Spray heads (efficiency – 70%)
- Rotors (efficiency – 70%)

It is not possible to determine the type of irrigation being used from aerial photographs and sometimes not possible from ground observations. Therefore it was assumed that turf areas were irrigated with either spray heads or rotors and non-turf areas were irrigated with drip.

Calculating Theoretical Irrigation Requirement

In its simplest form the theoretical irrigation requirement is a function of local reference evapotranspiration (ET_o), rainfall, landscape area, and plant material. Typically each landscape is composed of several smaller sub-areas each with its own characteristics of plant type, microclimate, and density. The equation used for estimating the TIR for this study was:

$$TIR = 0.624 \times ET_{o\ net} \times \sum_{i=1}^{n} \left[\frac{A_i}{Eff_i} \times K_{zi} \right]$$

Where:

TIR= theoretical irrigation requirement (gal)

0.624= converts from inches of net ET to gallons per square foot

$ET_{o\ net}$ = reference ET_o (inches) minus effective rainfall (inches)

n= number of zones in the landscape

i= individual zone

A_i= area of individual zone (sf)

Eff_i = efficiency of individual irrigation zone

K_{zi}= coefficient for individual zone

After the TIR was calculated for the landscape it was compared with the estimated outdoor use for the same time period. Residents who are applying the appropriate amount of irrigation to the landscape will have outdoor use that closely matches the TIR. There will be some residents who apply less than and some who apply more than the TIR. Customers who apply more than the TIR may benefit from an irrigation audit, landscape upgrades, or the installation of a weather-based irrigation controller. When customers are not over-irrigating the only way to reduce their outdoor use is to modify the landscape itself, either by replacing high water use plants with lower use types, or by reducing the irrigated area on the site.

The TIR was calculated based on the zone-by-zone analysis of the landscape coefficient (K_z). This allowed the requirement to be determined in a way that accurately took into account the varieties of landscapes and the mixtures of different conditions at the level of the irrigation zone. The actual water use, however, could not be determined on this level of detail because it was impossible to determine from the flow traces precisely which zone was being irrigated by each portion of a typical irrigation system cycle. No attempt was made to break up irrigation use occurring during the logging cycles into zones since this was not part of the workplan for determing ourdoor use, which was based on annual outdoor use, as described above.

Household Post-Retrofit Water Use Information Provided

After the baseline data were collected and analyzed a sample of the homes were selected to participate in a retrofit study. This resulted in a change-out of their fixtures and appliances to best available technology (from the perspective of water use). Following the retrofit a second set of flow trace date were collected to allow water use to be re-evaluated. This allowed a comparison of daily household use to be made. This was a critical step in setting goals for single family water use that are reasonable and achievable as part of the Water Authority long range water resources plan.

Results of Surveys

This section describes the results of the mail survey described in the Methodology section. The following tables provide summaries of the customers' responses to the survey questions. These indicate what the customer understood to be the case for their households, and may reflect errors based on misunderstandings about questions in the survey or household fixtures. A compilation of survey responses is provided in Appendix A.

Response Rates to Surveys

Table 5 shows the response rates to the surveys that were mailed to homes that received any rebate and homes that received no rebate. The overall rate of return showed that homes receiving rebates returned more of their surveys (19%) than homes receiving no rebate (12%). In all, the survey response rates were more than adequate for our data needs. Because of the uneven return rate between the rebate and non-rebate groups, weighted averages are provided to aid extrapolation to the overall population.

Table 5: Survey response rates

Group	Number of Mailed Surveys	Responses	Response Rate (%)
Any rebate	1500	292	19%
No rebates	1500	184	12%

Household Characteristics

Table 6 shows the number of persons per household in the survey respondents. One thing that stands out is that homes receiving rebates tended to have slightly fewer adults and children than non-rebate homes. The end result was that the rebate homes had an average of 2.38 persons per home, while the non-rebate homes had 2.53 persons. The weighted average was 2.47 persons per home. These data were used to generate per capita data. The per capita data were used for developing relationships between indoor water use and persons per home, which are the strongest explanatory relationships for residential indoor water use. Having the relationships between household use and number of residents allow us to normalize household water use and properly correct for the impact of the different number of persons per household.

Table 6: Average number of persons per household

Group	Adults	Children	Mean Household Size
Any rebate(s)	1.93	1.24	2.38
No rebate	2.03	1.29	2.53
Weighted Average	1.99	1.27	2.47

Average and median income data are shown in Table 7. The slight difference between median and average within the groups indicates that the average is skewed slightly by higher-end incomes. Both the average and median income reported by the occupants of the rebate-receiving homes was higher than that of the non-rebate homes. Overall the median income reported by the occupants in the rebate homes was 18% greater than that reported by the non-rebate home occupants.

Table 7: Reported income data

Group	Average Income	Median Income
Any rebate	$ 68,633	$ 65,000
No rebates	$ 58,034	$ 55,000
Weighted Average	$ 62,016	$ 55,000

As shown in Table 8, the majority of homes were built prior to 1980. The rebate-receiving group led the mid-range age category. However, homes that did not receive any kind of rebate were significantly represented in the newest home category (1995 to 2006).

Table 8: Age of home

Group	% Built before 1980	% Built 1980-1994	% Built 1995-2006
Any rebate	60%	25%	15%
No rebates	57%	15%	28%
Weighted Average	58%	19%	23%

On average there were approximately 3.2 bedrooms in the rebate-receiving homes and 3.1 in the non-rebate homes (Table 9). The weighted average is 3.1 bedrooms per home. The number of bedrooms is not as good a predictor for water use as is the number of residents, but can serve as a proxy when occupancy data are not available.

Table 9: Number of bedrooms reported

Group	Bedrooms
Any rebate	3.2
No rebates	3.1
Weighted average	3.1

Fixtures and Appliances

Table 10 shows the number of toilets in the homes and the percent of the toilets that the users believe to be ULF or better models. The survey data show that 88% of the toilets in the rebate homes are ULF or better toilets. For homes that did not receive any kind of rebate, the number is even higher: 93%. If the residents are correct then this implies a very high penetration rate of ULF or better toilets in all homes (the weighted average is 92% ULF or better). It should be kept in mind that because some homes have all ULF toilets and some homes have none, one would not find 92% of toilets in all homes to be ULF. Even with 92% of the toilets being ULF or better, there could still be a sizeable number of homes with no ULF or better toilets.

Table 10: Number of toilets per home and toilet flush types

Group	Toilets	% Standard	ULFTs		HETs		Dual Flush	
Any rebate	2.3	12%	1.5	66%	0.4	16%	0.1	6%
No rebates	2.2	7%	1.3	61%	0.4	20%	0.3	12%
Weighted average	2.2	9%	1.4	63%	0.4	19%	0.2	10%

Generally, the homes in the survey group averaged 2.1 showers per home (Table 11), with the rebate homes tending to have a slightly higher average shower count than the non-rebate homes (2.1 versus 2.0). Low flow showerheads (2.5 gpm or less) were reported in 44% of the rebate homes and 35% in the non-rebate homes.

Table 11: Showers and showerhead types

Group	Number of showers	Number of ULF showers	% ULF showers

Any rebate	2.1	1.0	44%
No rebates	2.0	0.7	35%
Weighted average	2.1	0.8	39%

Clothes washers are prevalent in the homes. Ninety-eight percent of the rebated homes and 94% or the non-rebated homes reported having a clothes washer. In homes receiving rebates, 50% of clothes washers are front-loading, high-efficiency models according to the respondents. This number drops precipitously for homes that did not receive rebates: only 16% reported having a front-loading, high-efficiency clothes washer. Table 12 shows the breakdown. It should be noted that the weighted average indicates 30% of clothes washers are front-loading, high-efficiency models.

Table 12: Clothes washers and clothes washer type

Group	Clothes Washer	Front Loader
Any rebate	98%	50%
No rebates	94%	16%
Weighted average	96%	29%

The preponderance of homes, both rebated and on-rebated, have garbage disposals and dishwashers. Utility sinks are present in around a quarter of the homes, as shown in Table 13.

Table 13: Incidental kitchen and faucet fixtures

Group	Garbage Disposal	Dishwasher	Utility Sink
Any rebate	82%	85%	30%
No rebates	76%	78%	21%
Weighted average	78%	81%	25%

There is definite presence of evaporative coolers in both rebate and non-rebate homes (Table 14). In arid climates, this type of cooling offers an effective and energy-efficient alternative to standard air conditioning. However, it is worth noting that the water consumption of an evaporative cooler can be significant.

Table 14 shows that a weighted average of 11% of respondents indicated the presence of a whole-house water treatment system. The water treatment systems tend to be found in systems with higher salinity water. There are two types of water treatment systems of interest. There are ion exchange water softeners that remove calcium and magnesium ions to soften the water, but have little impact on overall TDS of the product water. These devices use water only when they are recharged, as salt water is flushed back through the resin to recharge them and discharged to a drain. Reverse osmosis systems use water constantly when they are treating water. Usually around 20% of the water goes to a tank of product water and 80% goes down the drain (or, hopefully, in some cases to irrigation) as reject water. If only water for drinking is treated with RO the overall water use will be small, but in some cases if all of the water used indoor is treated the water use can be several hundred gallons per day.

Table 14: Evaporative coolers, treatment and spas

Group	Evaporative cooler	Whole house water treatment	Indoor spa
Any rebate	71%	9%	7%
No rebates	76%	12%	3%
Weighted average	74%	11%	5%

Whirlpool bathtubs were found in about one quarter of the homes that responded to the survey (Table 15). The rate of whirlpool baths in rebate-receiving homes is higher than in homes that received no rebates (27% versus 21%). Multi-headed showers appear in 10% to 12% of rebate and non-rebate homes respectively, while indoor gardens or greenhouses are relatively rare in both groups.

Table 15: Whirlpool, greenhouses, multi-headed showers

Group	Whirlpool bathtubs	Multi-headed showers	Indoor garden or greenhouse
Any rebate	27%	10%	4%
No rebates	21%	12%	3%
Weighted average	24%	11%	3%

The percentage of homes that report irrigation is very high in both rebate and non-rebate homes (Table 16). Ninety-three percent of the rebate homes irrigate and 87% of the non-rebate homes irrigate. Overall, 87% of homes report irrigating their landscape. The rate of homes with alternate water supplies for irrigation (wells primarily) averages 20%. A slight majority of the homes that irrigate do so with automatic sprinkler systems. Sprinklers are found in 63% of the rebate-receiving homes and 54% of the non-rebate receiving homes.

Table 16: Irrigation, irrigation sources, and automatic sprinkler systems

Group	% of homes that irrigate	% with automatic sprinkler systems	% with alternate supplies
Any rebate	93%	63%	23%
No rebates	83%	54%	18%
Weighted average	87%	58%	20%

Attitudinal Comparisons

Surveyed Water Authority customers responded almost unanimously that water conservation is critical for the future of Albuquerque (Table 17). Likewise, many said they conserve because it is the right thing to do. Respondents who received rebates were slightly more like to see water conservation as a means of saving money. Both groups were nearly equal in considering water conservation as a step towards energy conservation.

Table 17: Attitudes about water conservation, showing percent of respondents saying they agree with the statement

Group	Conservation of water is critical for the future of Albuquerque	I conserve water because it is the right thing to do	I conserve water to save money	I conserve water to save energy
Any rebate	97.4%	98.4%	79.9%	81.9%
No rebate	97.9%	93.8%	74.2%	79.9%
Weighted average	97.7%	95.6%	76.4%	80.7%

Table 18 shows the attitudinal results for water cost-related questions. Roughly three-quarters of respondents (either rebate or non-rebate) agreed that the cost of water was an important factor in deciding how much water to use. A similar proportion also said that there should be financial penalties for excess water use. However, there was much lower support for increasing water rates to encourage conservation. About 58% (weighted average) of respondents indicated awareness of rebate programs. When it came to rebate awareness, rebate-receiving respondents showed a higher awareness of rebates offered by the Water Authority. While this is not surprising, it should be noted that there is a 14% difference in rebate awareness between rebate-receiving and non-rebate receiving customers so further education and customer awareness may be warranted.

Table 18: Financial attitudes for conservation and water rates, showing percent of respondents saying they agree with the statement

Group	The cost of water is an important factor for me when	There should be strong financial penalties for	Water rates should be increased to encourage water	I am aware of rebates offered by the Water

	deciding how much water to use	people who use too much water	conservation	Authority
Any rebate	74.3%	77.3%	33.9%	66.4%
No rebate	77.3%	74.7%	25.3%	52.6%
Weighted average	76.2%	75.7%	28.6%	57.9%

Question 28 of the survey provides some very interesting insights into the attitudes and opinions of the customers with regard to water management issues. The vast majority of customers (394 out of a total of 476 respondents) thought that customes should be able to monitor their water use, and even more (413) thought that the ability to monitor water use would improve water conservation efforts.

Another important fact from this question was that most respondents said they felt many Albuquerque households were not well informed about the city's water sources. On a positive note, almost two-thirds (weighted average) of residents indicated that they follow the Water by the Numbers program for irrigation, and virtually the entire sample (465/476) expressed their belief that conservation is critical to the future of Albuquerque.

Table 19: Water monitoring and awareness, showing percent of respondents saying they agree with the statement (from Question 28)

Group	Residents should be able to track their household water use by reading their own water meter	Households would conserve more water if they had an easier way to monitor their water use	Most households in Albuquerque know where their water comes from when they turn on the tap	I follow the Water by the Numbers program when setting my irrigation schedule
Any rebate	85.2%	86.2%	27.3%	69.4%
No rebate	77.8%	87.1%	31.4%	61.9%

Weighted average	80.7%	86.8%	29.8%	64.8%

The customers also expressed a overwhelming opinion that there should be strong financial penalties for people who use too much water in question 28F. A total of 361 expressed their agreement with this proposition out of 472 respondents. This represents over three quarters of the respondents favoring the use of financial penalties as a method of enforcing water conservation.

Pre-retrofit Water Use

The following sections provide detailed information on the water use of the Albuquerque Logging Group. These 209 homes were selected from the population of single family homes and their water use was approximately 10% greater than the population as a whole.

Annual Use of Logging Group

The annual water use of the single family population and the survey sample group was discussed in detail in the Methodology section of this report. The key findings of that investigation are summarized here:

- As shown in Table 20, the average annual water use for the entire single family population in Albuquerque in the study year was 95 kgal per year. Of this, two-thirds was used indoors and one-third was used outdoors, based on an analysis of the monthly billing data.
- The annual water use for the various rebate groups analyzed in the early stages of the study showed that their indoor water use was similar in all of the rebate groups, but those customers who had had rebates tended to have higher outdoor water use. This was attributed not to the rebates, but to the nature of the customers who had gone through the rebate process.

The decision was made, in consultation with the Water Authority, to select the logging sample from customers with higher annual water use in order to increase the chances of finding customers who might benefit from outdoor interventions. Therefore the Logging Group was selected from customers having an annual water use around 105 kgal. Table 20 provides a comparison of the annual water use patterns of the Logging Group and the population of all single family homes. These data are from the billing records and will thus not agree precisely with the data from the logging with respect to indoor vs. outdoor water use.

Table 20: Annual use of Logging Group and population

Parameter	Population	Logging Group
Number	151,987	209
Average Annual Use	94.8 kgal	103.2 kgal
Average Seasonal Use	31.7 kgal	37.6 kgal
Average Non-seasonal Use	63.0 kgal	65.6 kgal

Indoor Use of Logging Group

Using the event database created from the flow traces it was possible to segregate indoor and outdoor water use in the homes, and examine each type of use separately. This section of the analysis looks at indoor uses. Leakage is included among indoor uses, but it should be kept in mind that some of the leaks may be due to faulty irrigation systems, and it is often impossible to distinguish indoor from outdoor leaks. Evaporative cooling use was considered outdoor use. The analyses are also based on total household use (rather than per-capita use) since we did not want to normalize the data on a per-capita basis separately from the other important explanatory variables. Also, since most utilities do not know the number of residents living in each home it makes more sense to analyze consumption on a household basis, which is something that the billing data provides.

Total Indoor Use

The indoor use events excluded the irrigation events, which eliminated the confusion caused by winter watering. The indoor use also does not include evaporative cooling, which is classified as an outdoor use. This allows comparisons to be made between the indoor use in the Albuquerque homes and the other study homes, which generally do not have significant amounts of cooling use.

Table 21 compares the total indoor water use for the 209 Water Authority study homes to the results from the REUWS and the EPA retrofit study. These data show that the total indoor water use for the homes is lower than the REUWS sample from 1997 and higher than the consumption levels obtained in the EPA retrofit study group, which were typical single-family homes that were retrofit with high efficiency fixtures and appliances.

Figure 9 shows a histogram of the total indoor water use for the study homes. It is clear from this graph that there is potential for indoor water conservation savings in the homes within the Water Authority service area. The data show that 44% of the homes use more than 150 gpd, and are the best candidates for indoor water conservation measures. Approximately 15% of the homes are using more than 250 gpd for indoor uses and would be even better candidates. In interpreting these results it should be kept in mind that indoor use also includes leak type events, so the large indoor users are probably homes with significant volumes identified as leakage.

Table 21: Indoor water use in Albuquerque compared to REUWS and EPA Retrofit data

Parameter	REUWS (gpd)	Albuquerque Logging Group (gpd)	EPA Post-Retrofit Study (gpd)
Mean ± 95% C.I.	177 ± 5.5	138 ± 15.6	107 ± 10.3
Median	160	118.9	100
Std Deviation	96.8	114.7	50.9
N	1188	209	96

Figure 9 shows the percent of the homes that have indoor water use falling into the various bins shown along the X-axis of the graph. The values shown represent the top end of the bins and both the incremental and cumulative percentages are shown. For example, the graph shows that 85% of all homes use 200 gpd or less for indoor purposes (plus leakage). Conversely, this shows that 15% of the homes use more than 200 gpd indoors. When viewed from the perspective of the numbers of homes the homes in the larger consumption bins they seem relatively unimportant since there are so few of them.

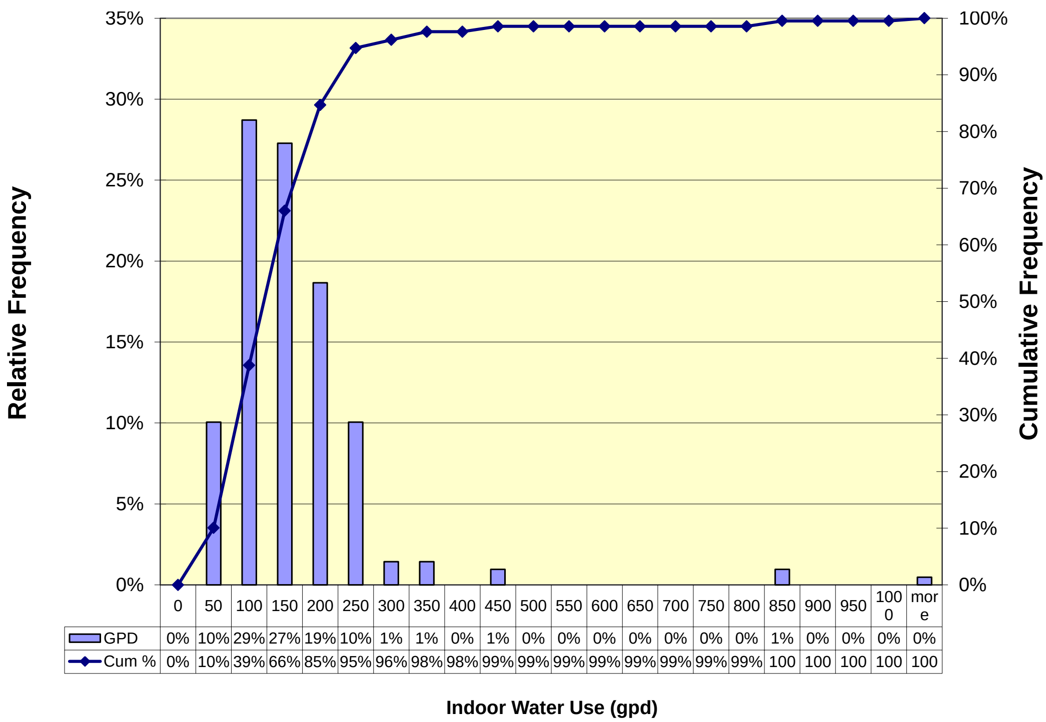


Figure 9: Percent of homes by daily consumption bin[9]

In Figure 10 the percent of the total daily indoor water use, accounted for by each consumption bin, is shown. When viewed from the perspective of the volume of use the larger bins are seen to be more important. For example, where only 15% of the homes used more than 200 gpd of indoor water these homes accounted for 32% of the total indoor use. The 1% of homes using more than 450 gpd for indoor uses accounted for 8% of all indoor use. This pattern where the homes in the upper bins account for a disproportionate volume of water use repeats itself for many types of use in the study.

10 Tier 3 clothes washers have a Water Factor of 4.0 which is the number of gallons required for each cubic foot of laundry. The amount of water used depends on the capacity of the clothes washer.

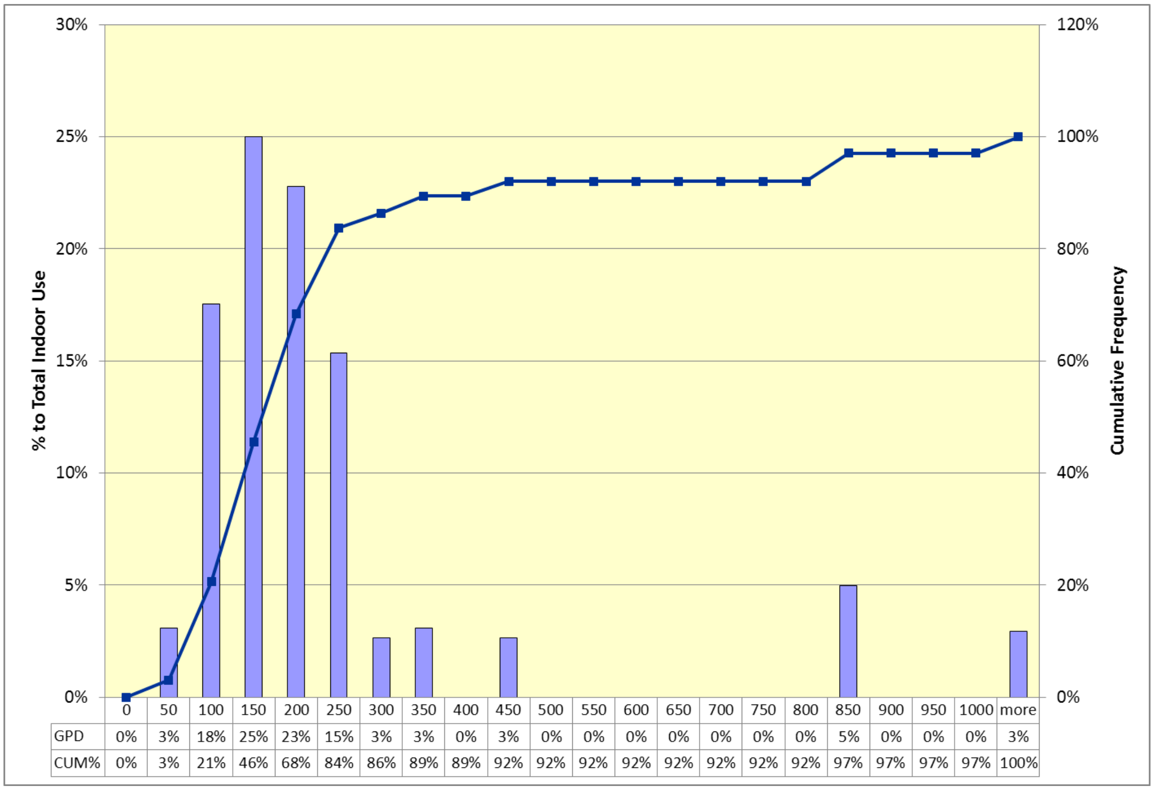


Figure 10: Percent of total indoor water use by daily use bin

Disaggregated Indoor Use

When indoor water use is examined in the Albuquerque study homes, it can be seen that five categories make up the bulk of indoor use: leaks, faucets, showers, clothes washers, and toilets. As shown in Figure 11 these categories make up over 95% of total indoor water use in the sample homes. As discussed above, water used for evaporative cooling was assigned as outdoor use.

Figure 12 shows the breakdown of indoor water use into its components in comparison to the REUWS group. This figure shows both the average daily use and the 95% confidence intervals for each category. The data show that the water use in the Water Authority group was significantly lower than that from the REUWS group for toilets and clothes washers, moderately lower for faucet and showers, slightly lower for baths, dish washers and "other", but was higher for "leaks". The reduction in toilets and clothes washer use appears to be related to the increased presence of newer equipment in the homes. The leakage rate in these homes was 16.8% of all indoor use, at 23.1 gpd. This is slightly higher than what was observed in the REUWS study group in 1996 and should be addressed further. The persistent leakage rates likely mask some of the anticipated gains from past clothes washer and toilet programs. The leak category should receive further study in order to determine the exact source of these events and the degree to which they are due to actual leaks from broken valves or pipes, or might be due to water-using devices that give the appearance of leaks, perhaps such as water treatment or cooling systems.

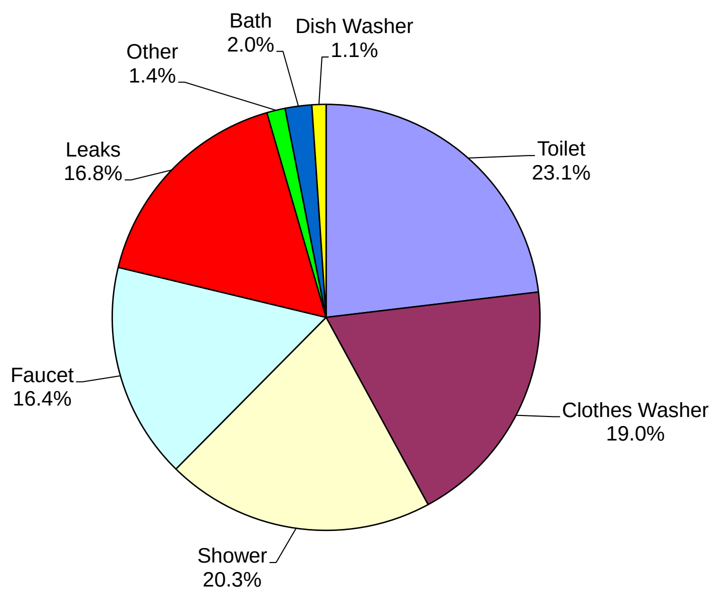
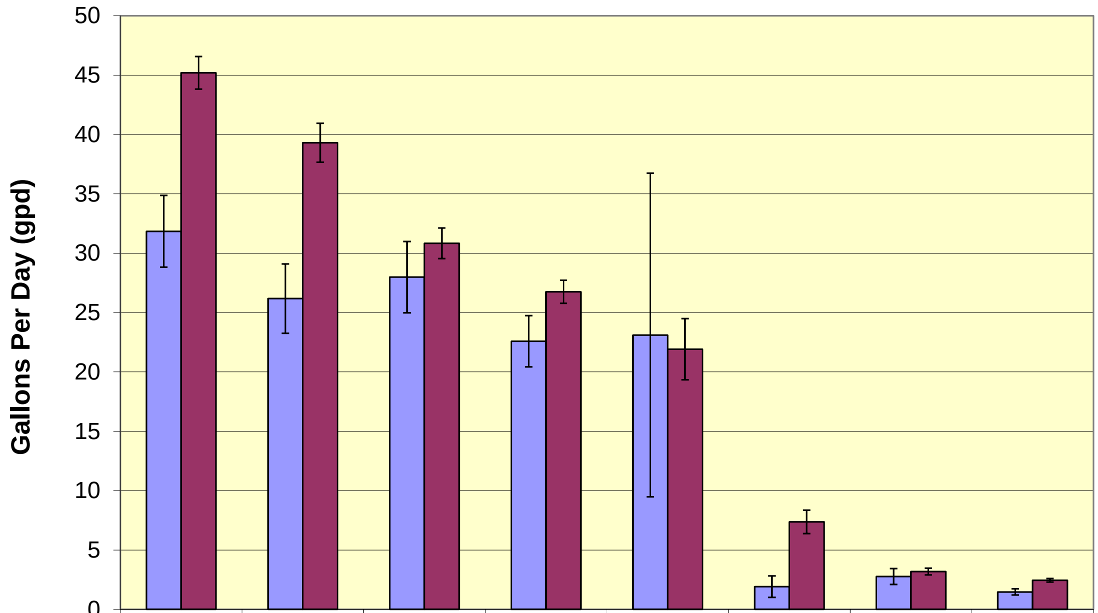


Figure 11: Indoor end-use pie chart for Albuquerque (% of total indoor use)



	Toilet	Clotheswasher	Shower	Faucet	Leak	Other	Bathtub	Dishwasher
Logging Group	31.84	26.18	27.99	22.58	23.11	1.92	2.77	1.47
REUWS	45.2	39.3	30.8	26.7	21.9	7.4	3.2	2.4

Figure 12: Comparison of household end-uses in Albuquerque Logging Group to REUWS

Toilet Use

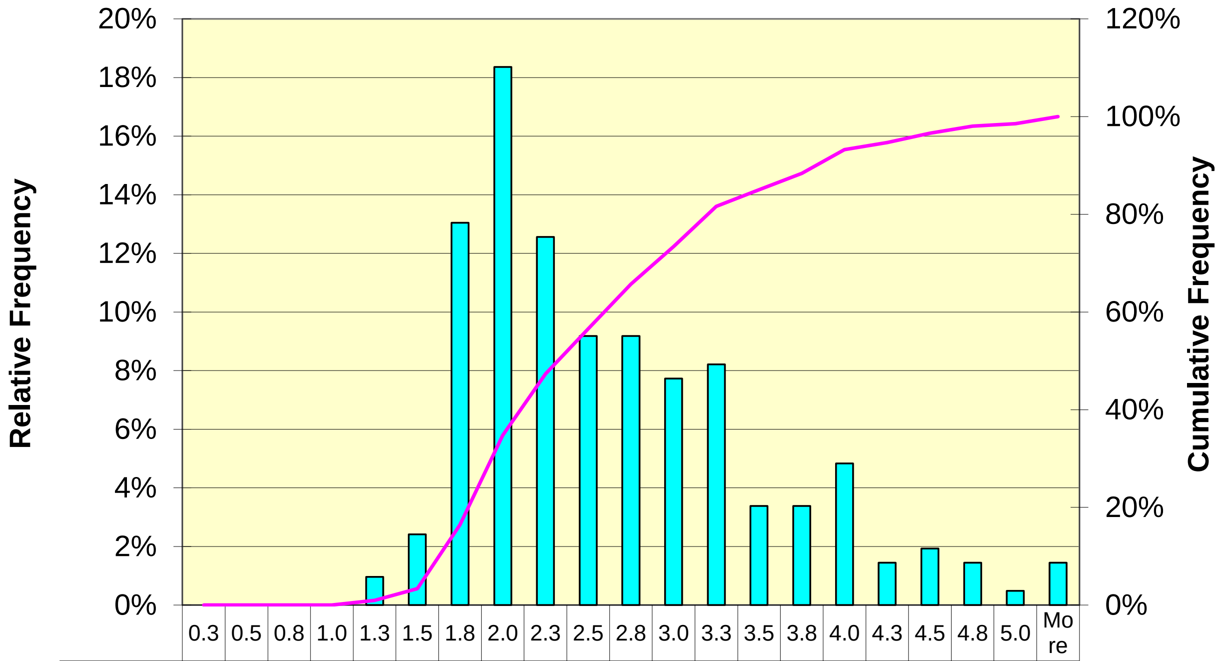
There was a total of 33,576 separate toilet flushes recorded by the data loggers during the logging period. This is equivalent to 12.8 flushes per house per day over approximately 12.6 days of logging. The distribution of toilet flushes is fairly normal, as can be seen from the fact that the median and mean values are so close to each other. The statistics for individual toilet flushes is shown in Table 22. The observation that there are a significant number of ULF toilets is indicated by the fact that on averge 49.7% of the flushes had average flush volumes less than 2.2 gal, which, allowing for error in toilet tank adjustment, classifies them as ULF toilets. At the same time the data show that there is still significant potential savings from toilet replacements in Albuquerque.

Table 22: Toilet flush volume statistics in Albuquerque

Parameter	**Value**

Total number of flushes in logging sample	33,576
Average flushes per household per day	12.8
Average toilet flush volume (gal)	2.54
Median flush volume (gal)	2.30
Average % of flushes less than < 2.2 gal	49.7%

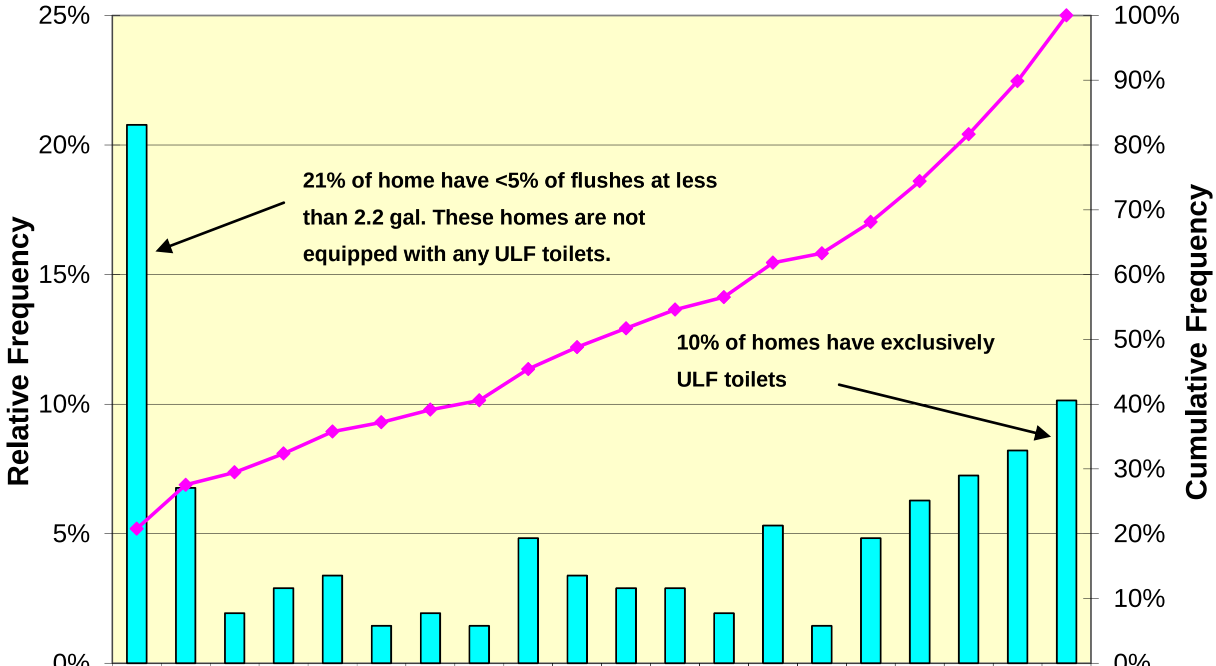
Figure 13 shows a histogram of the average flush volumes determined for each of the 209 logging homes in Albuquerque. These volumes were calculated by dividing the total toilet volume used by each home by the number of flush events recorded by the loggers. As such, the values represent the average of all toilets in the home. Homes in which the average gallons per flush is equal to or less than 2.0 gallons are deemed to meet the ULF criteria. This value was used as the criteria to define a home meeting the ULF criteria. Later in this report when mixtures of toilets in the homes are discussed we use a slightly higher value of 2.2 to capture individual flushes from poorly adjusted ULF toilets.



	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5	4.8	5.0	More
R Freq	0%	0%	0%	0%	1%	2%	13	18	13	9%	9%	8%	8%	3%	3%	5%	1%	2%	1%	0%	1%
Cum %	0%	0%	0%	0%	1%	3%	16	35	47	57	66	73	82	85	88	93	95	97	98	99	100

Figure 13: Average household toilet flush volume histogram

We know that many houses have a mixture of different types of toilets, including high volume toilets, which flush at or over 1.6 gpf, “ULF” toilets, which are the current standard, which are supposed to flush at 1.6 gpf, and high efficiency toilets “HET”, which are designed to flush at 1.28 gpf or less. In order to quantify the degree of heterogeneity in the homes the percent of flushes in each home that were less than 2.2 gallons was determined. This distribution is shown in Figure 14. Houses with 100% of their flushes less than 2.2 gallons are considered to be exclusively ULF or HET homes. Approximately 10% of the study homes had all of their flushes less than 2.2 gallons. At the other end of the spectrum, 21% of the homes had less than 5% of their flushes below 2.2 gallons. These homes probably do not contain any ULF or HET type toilets. The rest of the homes fall in between. The figure shows that there is still significant potential for water savings from toilet retrofits. In a perfectly retrofit system all of the homes would have 100% of their flushes less than 2.2 gpf.



	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100 %
GPD	21%	7%	2%	3%	3%	1%	2%	1%	5%	3%	3%	3%	2%	5%	1%	5%	6%	7%	8%	10%
Cum %	21%	28%	29%	32%	36%	37%	39%	41%	45%	49%	52%	55%	57%	62%	63%	68%	74%	82%	90%	100%

Percent of flushes < 2.2 gal

Figure 14: Toilet heterogeneity chart

Clothes Washer Use

During the logging period a total of 2,278 clothes washer loads were recorded by the data loggers on the 201 homes that had or used washers during the logging period. This averages to 0.9 loads per house per day over the 12.6 logged days per home in the sample. The median gallons per load was 31.7 gpl and the average was 30.4 gpl. Compared to the current Tier 3 standard for the Consortium for Energy Efficiency of approximately 15 gpl[10] the Water Authority stock of clothes washers uses water at over twice the best available technology rate, but still represents a significant improvement from the pre-NEPA generation of homes. A total of 37% of the houses had clothes washer use of less than 30 gpl, the benchmark being used in this study for high efficiency machines.

10 Tier 3 clothes washers have a Water Factor of 4.0 which is the number of gallons required for each cubic foot of laundry. The amount of water used depends on the capacity of the clothes washer.

Table 23 shows the summary statistics for the clothes washer data, and Figure 15 gives a histogram of the average gallons per load in the study homes.

Table 23: Clothes washer statistics in Albuquerque

Parameter	Value
Total number of loads in database	2,278
Average loads per household per day	0.9
Average gallons per load	30.4
Median gallons per load	31.7
% of houses with < 30 gpl	37%

The histogram of unit volumes shows two distinct peaks: one between 15 to 20 gallons per load and another between 35 to 40 gpl. The lower of these is certainly associated with high efficiency machines, which appear to meet the WaterSense criteria. The larger peak represents the stock of older, less efficient machines in the housing stock.

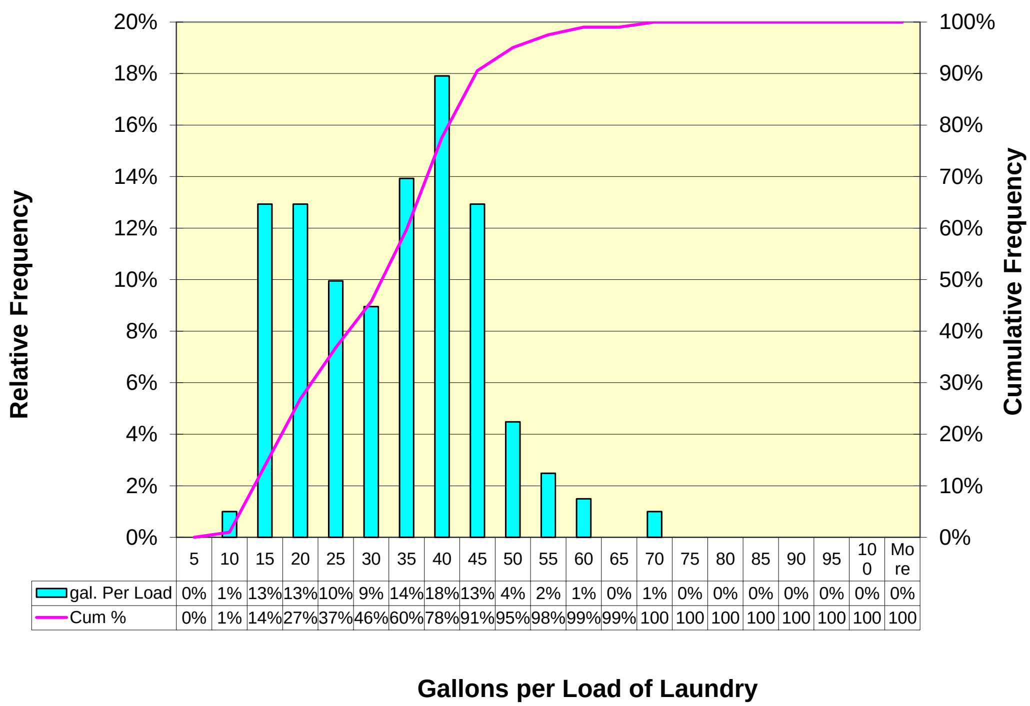


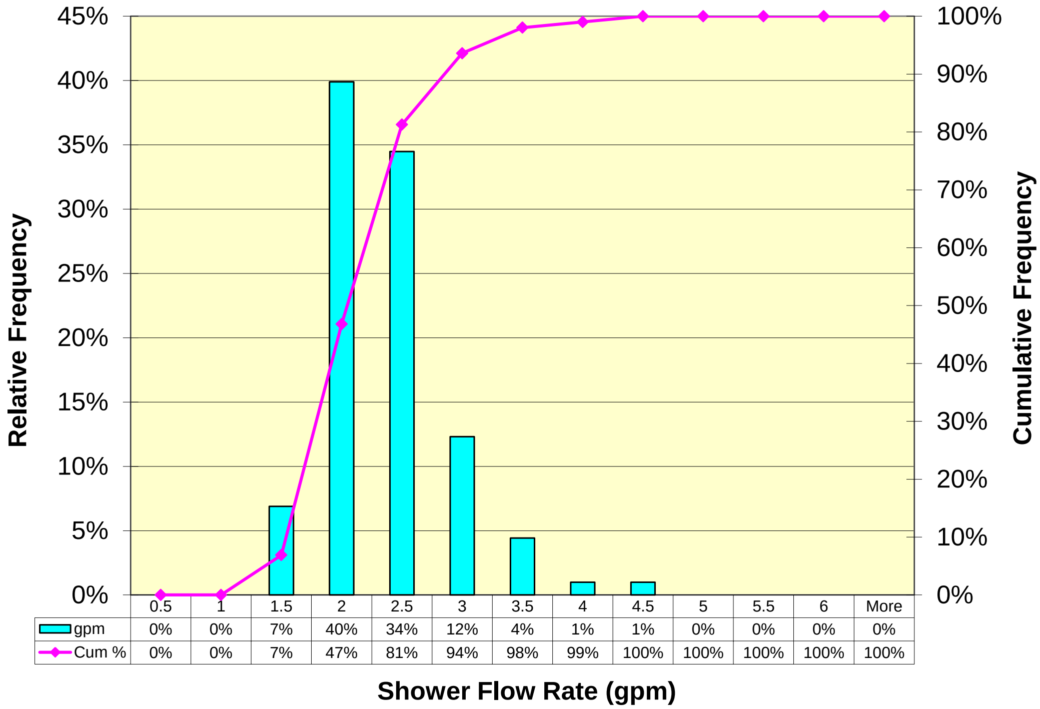
Figure 15: Distribution of clothes washer volumes

Shower Use

There were a total of 4,478 showers logged during the study period in the Water Authority study group. This averaged out to 1.7 showers per household per day. The average shower used 16.6 gallons of water, and the average shower flow rate was 2.1 gpm. Approximately 47% of all homes in the Water Authority sample used less than 2.5 gpm for showers. Histograms of flow rates and volumes are provided in Figure 16 and Figure 17 respectively. There is a lot of variability in shower volumes and in flow rates.

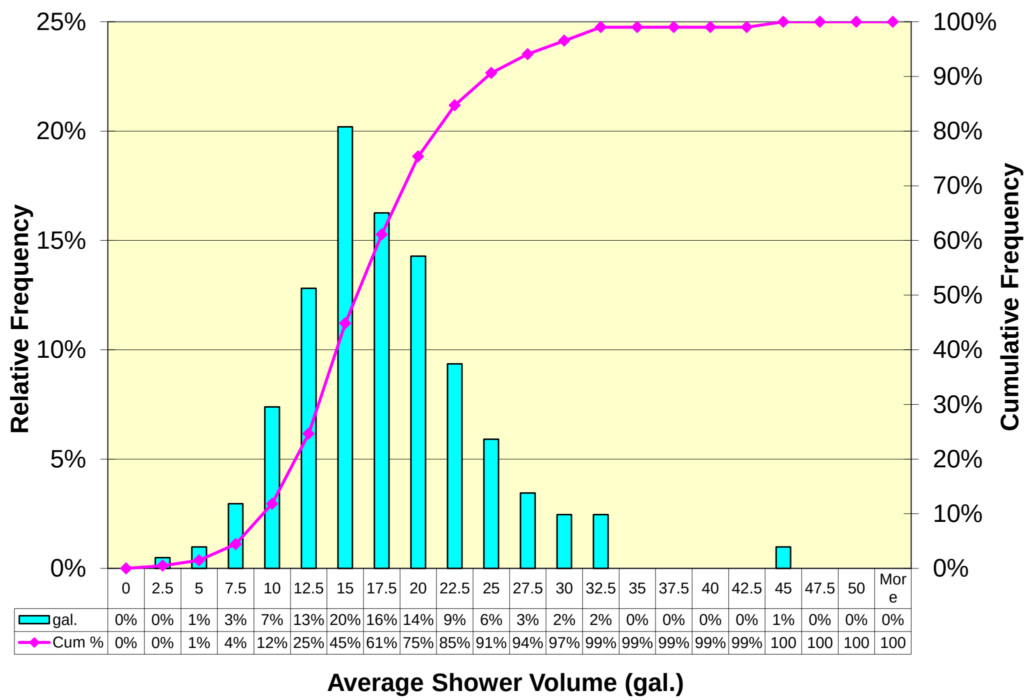
Table 24: Baseline shower statistics in Albuquerque

Parameter	Value
Total number of showers in database	4,478
Average showers per household per day	1.7
Average gallons per shower	16.6
Average shower duration (min)	7.9 ± 0.4
Average shower gpm	2.1
Median shower gpm	2.1
% of showers < 2.5 gpm	47%



	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	More
gpm	0%	0%	7%	40%	34%	12%	4%	1%	1%	0%	0%	0%	0%
Cum %	0%	0%	7%	47%	81%	94%	98%	99%	100%	100%	100%	100%	100%

Figure 16: Distribution of shower flow rates



	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	More
gal.	0%	0%	1%	3%	7%	13%	20%	16%	14%	9%	6%	3%	2%	2%	0%	0%	0%	0%	1%	0%	0%	0%
Cum %	0%	0%	1%	4%	12%	25%	45%	61%	75%	85%	91%	94%	97%	99%	99%	99%	99%	99%	100	100	100	100

Figure 17: Distribution of shower volumes

Leakage

During the logging period some leaks were recorded in all of the homes. Table 25 shows that the average leakage rate in the baseline homes was 23.1 gpd, while the median leakage rate was less than 1.7 gpd. This means that more than half of the homes had leakage rates less than 1.7 gpd while the remaining homes had large enough leakage rates to raise the average for the entire group to it observed value. The table also shows that 9% of homes had leakage rates of more than 50 gpd and only 4% of the homes had leakage rates of more than 100 gpd. It is difficult to say precisely where the leaks are occurring in these homes. They may be in the internal plumbing (often toilets) or in irrigation systems. This high value of leakage, however, warrants further investigation. In rare cases the homes may have some type of device that actually uses water on a continuous basis giving the appearance of a leak.

Table 25: Statistics on leakage in Albuquerque

Parameter	Value
Total number of days in database	2,649
Average leakage, gpd	23.1
Median leakage, gpd	1.7
Max leakage in set, gpd	974.8
% houses w/ leakage > 50 gpd	9%
% houses w/ leakage > 100 gpd	4%

The percentage of homes by bins of leakage is shown in Figure 18. This shows that 80% of the homes have leakage rates of less than 10 gpd and that the percentages drop off quickly in the higher bins. When the percentage of the average daily leakage volume is shown for the same daily leakage bins in Figure 19, the impact of the high volume leakage becomes much clearer. In this figure we see that the percent of the total leakage volume accounted for by the homes leaking at more than 50 gpd is 53%. In other words, the 8% of homes leaking at more than 50 gpd account for 53% of all leakage. Similarly, the 4% of homes leaking at 100 gpd or more, account for 40% of total leakage.

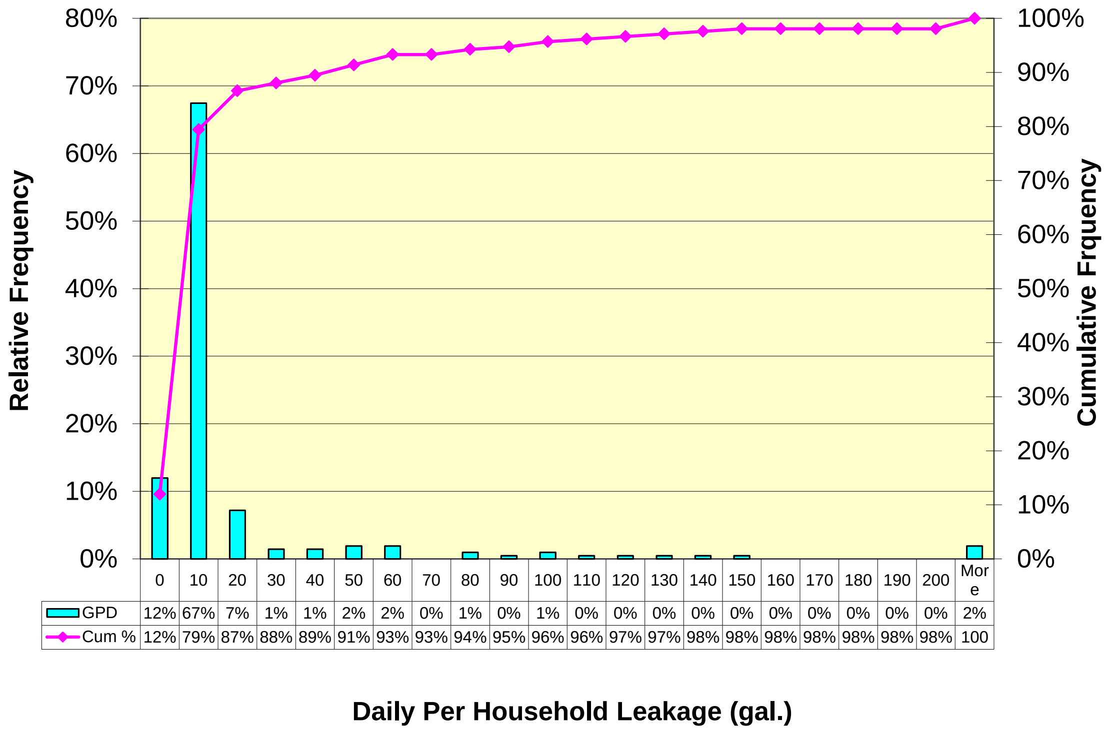


Figure 18: Percent of homes by leakage bin

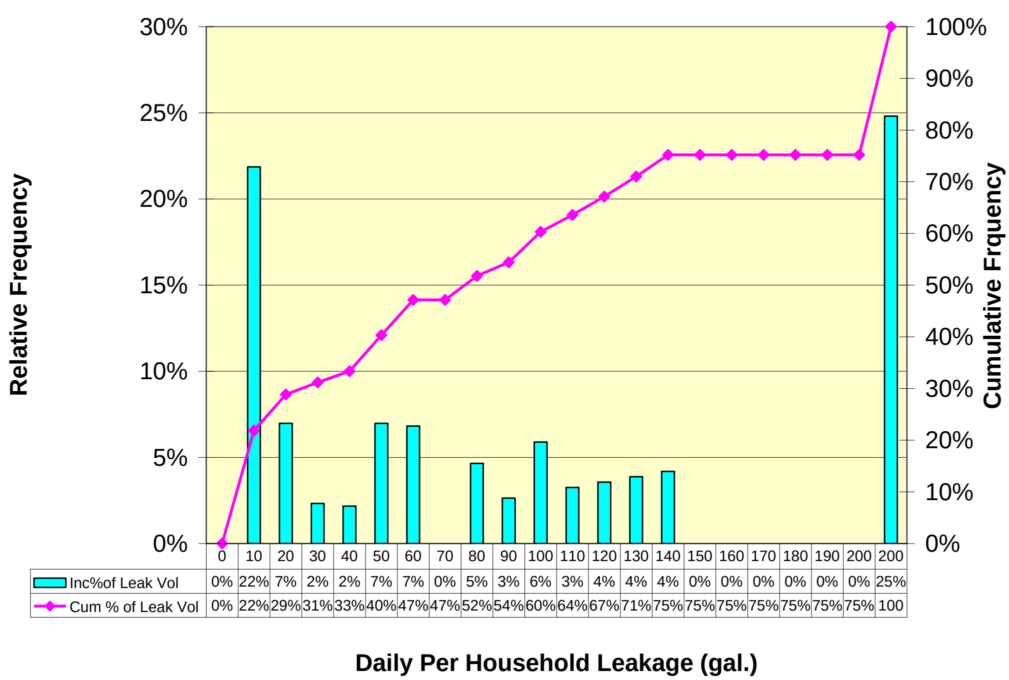


Figure 19: Percent of total leak volume by bin

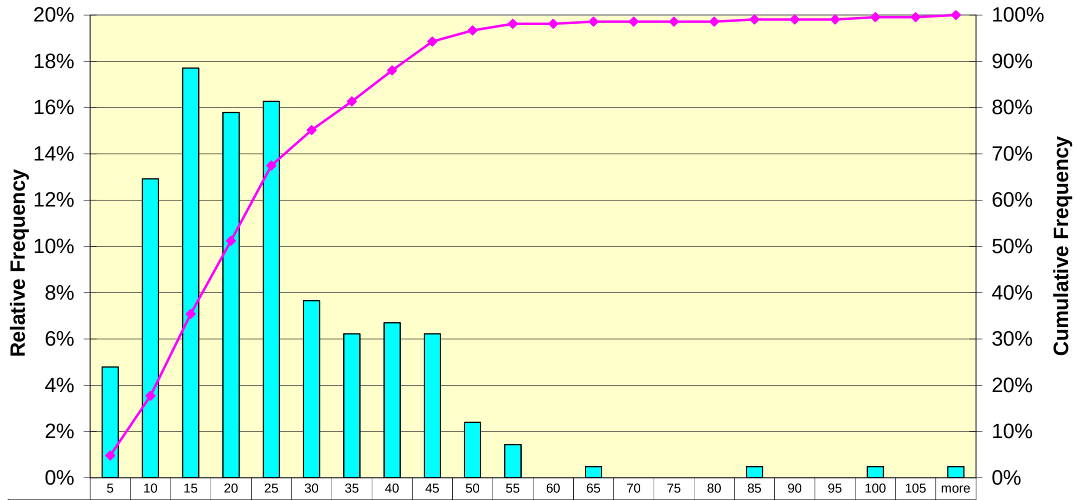
Faucet Use

The miscellaneous faucet use category contains most of the use events that do not fit into any of the other categories. It is possible that water used for bathing could show up as miscellaneous faucet use if the event that created the water use did not match either a shower or bathtub pattern. Filling a basin with a couple of gallons of water to wash a child would most likely show up as faucet use. The same holds true for filling a bucket to wash a car or change the water in an aquarium. It represents general domestic uses in the home drawn from all of the faucets in the home.

The average home in Albuquerque used 22.6 gallons per day for miscellaneous faucet uses, while the median use was 19.4 gpd. This is a fairly normal distribution, but there are a few homes with significantly larger amounts of faucet use. The highest recorded faucet use was 131 gpd. There were a total of 126,471 faucet events in the Albuquerque event database. Figure 20 shows the distribution of daily household faucet use in the study homes. Seventy-five percent of the homes used 30 gallons per day or less for faucet use. The average duration of faucet events was 34.8 seconds.

Table 26: Faucet statistics in Albuquerque

Parameter	Value
Total number of days in database	2,640
Average faucet use, gpd	22.6
Median faucet use, gpd	19.4
Average faucet duration (seconds)	34.8
Max faucet use in set, gpd	131
Number of faucet events	126,471



	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	more
GPD	5%	13%	18%	16%	16%	8%	6%	7%	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum %	5%	18%	35%	51%	67%	75%	81%	88%	94%	97%	98%	98%	99%	99%	99%	99%	99%	99%	99%	100%	100%	100%

Daily Per Household Faucet Use (gal.)

Figure 20: Distribution of household faucet use (gpd)

Per Capita Use Relationships

The main factor affecting indoor water use other than the nature of the fixtures and appliances in the homes was the number of residents. Figure 21 shows the indoor water use in gpd versus the number of residents in the home for the Albuquerque baseline sample, the REUWS sample from 1997 and the EPA Retrofit Study from 2000. All three samples show similar relationships between indoor use and the number of residents, but the REUWS homes show the highest use and the EPA Retrofit study the lowest. The Albuquerque data are in the middle of the two other reference studies, but lie closer to the high efficiency Retrofit group than they do to the REUWS sample.[11]

The relationship from Figure 21 can be used to normalize the indoor water use for a similar number of residents so that comparisons can be made independent of the effects of the residents. Table 27 shows the predicted household use for a family of three for the three sample groups. This shows

[11] Data from six outliers in Albuquerque were excluded from the indoor data because they clearly were out of sync with the rest of the data.

that the indoor use for the Albuquerque sample lies 40% of the way between the EPA group and the REUWS group. The lower indoor water use for a standard household size is due to the higher efficiency of the indoor use in Albuquerque compared to the REUWS group when the number of residents is constant.

Table 27: Normalized household use comparisons

Sample	Relationship	Household Use for Family of Three
REUWS	$y = 87.41\ x^{0.69}$	187
Albuquerque Logging Group	$y = 67.26\ x^{0.7034}$	146
EPA Retrofit	$y = 50.21\ x^{0.77}$	117

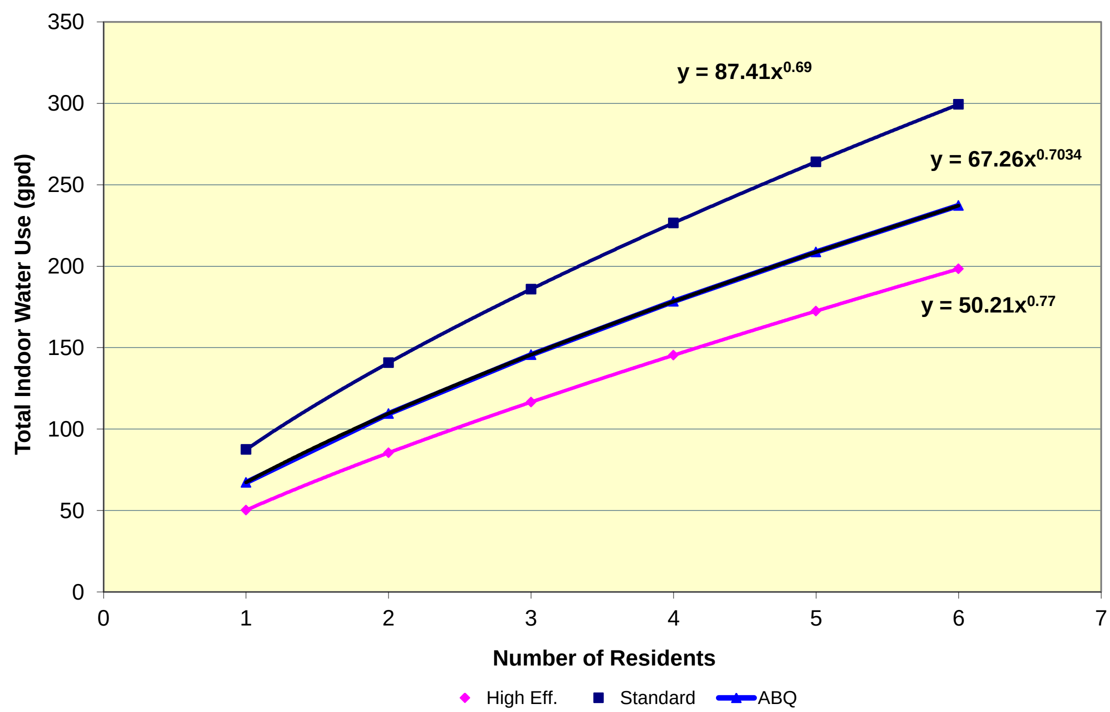


Figure 21: Indoor use versus the number of residents

Household Efficiency Rates

One of the main goals of this project was to determine the percentage of homes that are equipped with high efficiency fixtures and appliances. For this study the data from the logging results provided household water use for toilets, clothes washers and toilets, which could be expressed on the basis of the efficiency of each device, or, gallons per flush for toilets, gallons per load for clothes washers and gallons per minute for showers.

Frequently, water agencies attempt to make determinations through residential audits, which require a technician to enter the house and examine the toilets, showers and clothes washers. Besides having to schedule a home visit this technique requires that the homeowners volunteer to participate in the program, which leads to questions about bias in the results. Also, observing the make and model of the devices installed in the home is no guarantee of their actual water use. With data loggers a strict random sample can be drawn from the customer database (as was done in this study) and the necessary analyses done to determine their efficiency status. All of the houses had toilets in the traces, but not all had shower or clothes washer events, so the percentages for these devices was based on a ratio of the number of homes with high efficiency showers and clothes washers to the total number of homes having showers and clothes washers present in the trace.

In order to qualify as high efficiency each home had to meet the criteria for each device shown in Table 28. These are unofficial criteria based on experience as to what has constituted an efficient device over time. The newest technologies exceed these criteria, but we continue to use them since they allow for comparisons among different study groups. The results of the analyses for the Albuquerque Logging Group are shown in Figure 22. This figure shows both the mean household penetration rates and the minimum expected rate at a 95 % confidence level.

Table 28: Efficiency criteria for penetration rate determination

Device	Criteria
Toilets	Ave gallons per flush < 2.0 gpf
Showers	Ave shower flow rate < 2.5 gpm
Clothes Washers	Ave load uses < 30 gal

The data from Albuquerque indicate that approximately 35% of the houses meet the criteria for ULF toilets, while 46% meet high efficiency criteria for clothes washers, and 81% meet the shower criteria.

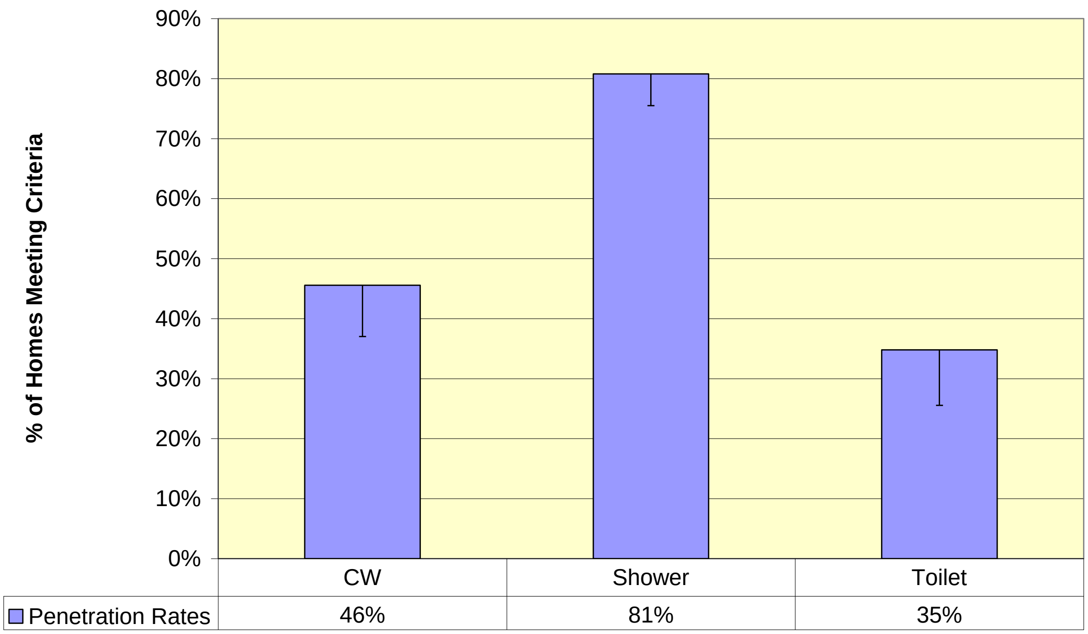


Figure 22: Logging Group household compliance rates for toilets, showers and clothes washers

The data in Figure 22 represent the percentage of households that met the efficiency criteria. In the case of clothes washers, where there is only one unit per home, the household percentages are equivalent to the percentage of all machines in the service area. So, it is safe to assume that 46% of homes and appliances are using 30 gpl or less. For toilets, however, the percentage of homes that meet the criteria will be less than the percentage of toilets. This is because all of the toilets in the home need to be ULF or better models in order to have the average flush volumes less than 2.0 gpf. A home with one ULF model and one high volume model will have an average flush volume greater than 2 gpf. It is impossible to say precisely what percent of toilets are ULF or HET models without going into the homes to examine them, but we do know from other studies that percentage of ULF or better toilets will be up to twice that of the percent of homes meeting the criteria.

Another way of illustrating the lag between toilet penetration and household penetration is to imagine a group of 100 homes having 2 high volume toilets each flushing at 3.5 gpf. This would represent a total of 200 toilets. If 100 of these were retrofit with ULF devices flushing at 1.6 gpf the average flush volume of all of the homes would be around 2.5 gpf. None of these homes would pass the 2.0 gpf criteria, so that even with 50% of the toilets replaced we would have 0% of the homes meeting the criteria. As the next 100 toilets were upgraded however, the household percentage would rise from 0% to 100%. That is what we are seeing in the data from this sample.

Discussion of Indoor Use

The indoor use results for Albuquerque show that the single-family homes in the service area consume less water than the "standard" single-family homes in terms of their total daily household indoor use. The REUWS group from 1996 averaged 177 gphd and the 2009 Albuquerque group averaged 138 gphd for all indoor uses. One explanation for the study homes water use being lower than the average homes from the REUWS is the measured decrease in water use for clothes washers and toilets, which shows the impact of the new technologies for these categories of water use. The results from the in-home surveys show that the average number of persons per home in this group was 2.45, which is lower than the average number of 2.7 residents in the REUWS study. This would also contribute somewhat to the lower household use, but as shown in Figure 21 when corrected for the number of residents the household use in the Albuquerque group is still lower than the REUWS group.

The leakage rates in these homes, however, were just slightly higher than is normally seen in these populations. This could be due to leaks in indoor fixtures and appliances or due to leaks in irrigation systems, both of which are fed by the same meter in most cases. In any case it appears to be worthwhile to do some further investigation of leakage to see if it can be reduced. If leakage could be eliminated it would bring the average daily indoor use down to 132 gpd, which would be in the very efficient level. There are devices that can recognize and interrupt leaks. These should be tested by the Water Authority.

The data for the fixture penetration rates show that while progress has been made there is still potential for both toilets and clothes washer replacements. Only 35% of homes met the ULF toilet criteria and 46% of the homes met the high efficiency clothes washer criteria. That means that nearly 64% of the homes require some level of toilet upgrades and 51% of the homes need a high efficiency clothes washer upgrade. Over time, as the remaining low efficiency devices are replaced, the household efficiency rates should increase significantly. The average shower flow rate is low enough that there is no reason to do any retrofits of showerheads, except with devices that use less than 2.0 gpm. There are several good showers that use 1.75 gpm and these are the ones that should be included in any new retrofits. All of the showers used for the retrofit had flow rates of 1.7 gpm or less.

According to the Water Authority billing records there are approximately 151,978 single-family accounts in the service area. The average indoor water use in the current study group was 154 gphd. It is reasonable that this could be reduced to at least 120 gpd by employing best technologies, as demonstrated by the EPA Retrofit Study (See Table 21). Assuming that the logging sample is typical, which it appears to be, implies that an annual savings of nearly 12.4 kgal/year/account is achievable over time from indoor conservation measures. Projected to the entire population this is equivalent to an overall savings of 1,886 million gallons, or 5,788 acre feet per year from interior retrofits and upgrades to the single-family homes in the Water Authority service area. This estimate is based on a simple comparison of means, and is meant to show the general size of the potential savings. As will be seen in the discussion of water savings based on more detailed analyses of the data, the actual potential sav ings are significantly greater than the estimate based on a comparison of the means.

Outdoor Use of Logging Group

Irrigation use was estimated by taking the total annual water use for each home from the billing data and subtracting the projected indoor use based on the flow trace data or the average winter use. The GIS analysis for each lot provided information on the total lot sizes (verified against site visits), and the irrigated areas. In addition to the outdoor use for irrigation, there was an average of 16 gpd used for evaporative cooling in the logging homes during the logging period. The statistics for outdoor water use from the logging sample are shown in Table 29.

Table 29: Outdoor water use in logging sample

Outdoor Water Use	(kgal)
Mean for irrigation	48.8
Mean for evaporative cooling	16.0
Median	28.6
Minimum	0
Maximum	504

Count	209
Confidence Level (95%)	8.9

Irrigated Areas versus Lot Sizes

Table 30 shows the statistics for the lot size and irrigable areas of the 209 homes in the outdoor use database for Albuquerque. The average lot size was 9,506 square feet and the median lot size was 7,616 square feet. There was a wide range of lot sizes from 1,784 to 119,093 square feet. On average, only about a third of the lot was irrigated; this is typical since some portion of the lot is non-irrigated native land, and some is occupied by the footprint of the house, the driveway, and other hardscape. The average irrigated area was found to be 3,207 square feet and the median was 2,541 square feet. The amount of irrigated area ranged from a low of 48 square feet to a high of 39,030 square feet.

Table 30: Lot size and irrigable area data for Albuquerque

Lot Size (sf)		Irrigated Area (sf)	
Mean	9506	Mean	3207
Median	7616	Median	2541
Minimum	1784	Minimum	48
Maximum	119,093	Maximum	39,030
Count	209	Count	209
Confidence Interval (95%)	1474	Confidence Interval (95%)	497

Besides irrigable area, the next most important factor in determining the theoretical irrigation requirement was the reference evapotranspiration (ET_o) for the area. For the Water Authority service area the ET_o from the Candelaria local weather station was used to estimate irrigation demands. The ET_o data were corrected for rainfall to generate net ET_o data. Net ET_o averaged 97% of ET_o based on an analysis of daily rainfall and soil moisture balances versus ET for the weather station.

Table 31 shows the data for the weather station used for determining the irrigation requirements for Albuquerque. Both the inches of demand and gallons per square foot are shown. These demands are for the reference crop, which is cool season turf at 4" - 7" height. In order to use this to determine the theoretical irrigation requirement for other landscape types, a crop coefficient must be applied. For this study a factor of 0.8 was used for turf, 0.30 was used for xeriscape, and 0.8 was used for shrubs, tree canopy and vegetable gardens. A "crop coefficient" of 1.25 was assigned to swimming pools in order to allow for their water requirements.

Table 31: Net ET_o from Candelaria Weather Station in Albuquerque

Candelaria Weather Station	Net ET_o	
	GPSF	Inches
Average	40	64

Figure 23 shows the relationship between irrigated area and lot size with the best fit line plotted. The equation shown on the figure gives a fairly good model of irrigated area, having and R^2 value of 50%. Overall, the best fit relationship is that irrigated areas equate to approximately 36% of the total lot size of the lots in the sample.

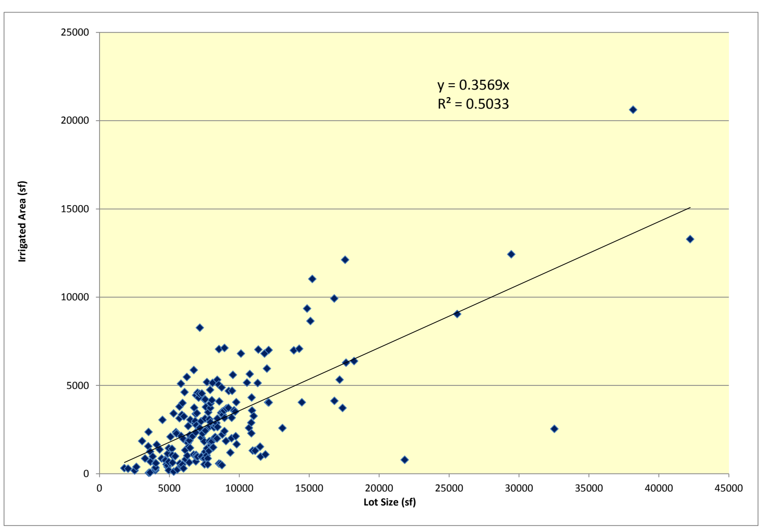


Figure 23: Irrigated area versus lot size for Albuquerque

Reference and Theoretical Irrigation Requirements

The reference application assumes a perfect irrigation system irrigating a total turf landscape. It is useful primarily as an indicator of how a system's irrigation demand is linked to ET for a reference landscape type, and how the water use of the actual landscape compares to a total turf landscape. The reference requirement will always be equal to the net ETo times whatever crop coefficient is being assigned to turf. In our case, with a crop coefficient of 0.8 and a net ETo of 64 inches the reference requirement is 51.3 inches.The next logical step is to determine the theoretical irrigation requirement (TIR) for the lots based on their actual landscapes and after making reasonable allowances for irrigation efficiencies assuming a well-designed and maintained irrigation system.

Table 32 shows both the reference and theoretical irrigation requirements for Albuquerque. The reference demand, shown in the table, represents the average amount of water that would be required to irrigate the landscapes of the logging sample if they were planted exclusively in turf. The theoretical demand shown next to these represents the best estimate of the actual average water requirement of the landscapes as they existed during the study period based on the aerial photo interpretations and site visits.

The theoretical demands are reduced from the reference requirements by the fact that the landscapes are not entirely turf, which reduces their landscape coefficients, but they are also increased by the fact that the irrigation efficiencies are less than 100%.

We define the ratio of the theoretical to reference requirements as the *landscape ratio* since it expresses the relative demand of the actual landscape to a pure turf landscape. In Albuquerque the landscape ratio for the logging sample averaged 88% (112.9/127.9 = 0.88). This means that based on the assessment of the landscapes performed for this study in 2010 it would take an average of 112.9 kgal per year of outdoor use to supply 100% of the landscape requirements.

Table 32: Reference and Theoretical Requirement data in Albuquerque

	Net Reference Requirement		Theoretical Requirement	
	(kgal)	(in)	(kgal)	(in)
Mean	127.9	51.3	112.9	54.9
Median	101.3	51.3	84.31	55.4
Confidence Level	19.8	---	16.2	1.09

Application Ratios

The theoretical irrigation requirement shows the amount of water that the landscapes would require in order to satisfy the full plant requirements. A well designed system with an irrigation controller that matches actual applications to ET_o should apply this amount of water to the land. In fact, however, landscape use varies significantly from the theoretical requirements based on the understanding and personal preferences of the landscape owners, and how their irrigation systems are programmed.

For purposes of this study we have defined the term *application ratio* as the ratio of the actual application of irrigation water to the theoretical requirement. A plot of these values as a scatter diagram is shown in Figure 24. This figure shows a relatively weak relationship between actual irrigation use and theoretical requirements. This indicates that many customers are not adjusting their irrigation to ET conditions. The data also show that many customers for whom a TIR has been calculated appear to not be irrigating at all, and some customers are applying more water than is indicated from the TIR calculations. The best fit line on the figure has a slope of 39% of the TIR, which indicates that as a group the customers are applying significantly less than the TIR.

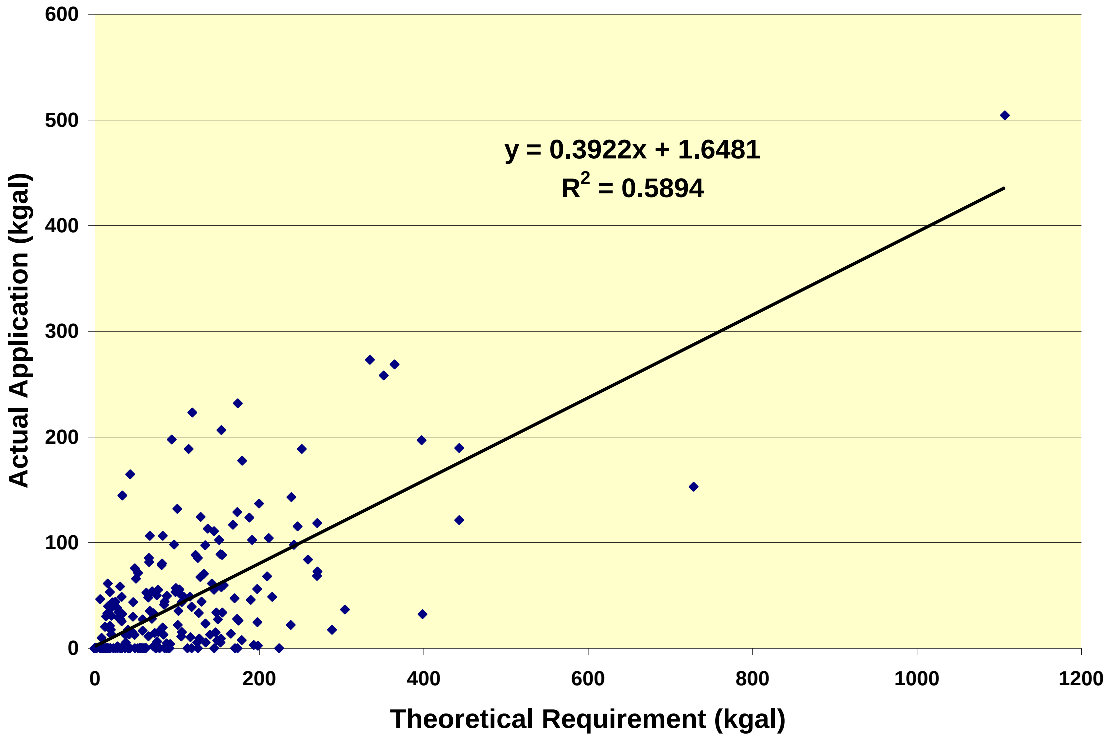


Figure 24: Actual versus theoretical applications for Albuquerque

Table 33 shows the statistics for the landscape and application ratios for the Albuquerque Logging Group. The landscape ratio is the ratio between the theoretical irrigation requirement on the lot and the reference requirement (based on ET_o). The application ratio is the ratio of the actual irrigation application to the theoretical requirement for each lot.

The application ratio shows whether the customers are matching their irrigation practices to the theoretical requirements based on the local ET_o and horticulture. In this case the data show that the actual application should be around 86% of the ET_o based on the average landscape, but the actual applications averaged only 56% of the theoretical requirement while the median application ratio was 31% of the theoretical requirement. This is an indication that there is very little over-irrigation by the average customers, and that excess irrigation is limited to a relatively small number of accounts.

Table 33: Landscape and application ratios – Water Authority

	Landscape Ratio[1]	Application Ratio[2]
Mean	0.86	0.56
Median	0.87	0.31
Confidence Level	0.02	0.11

[1] Landscape ratio = theoretical irrigation requirement/reference irrigation requirement

[2] Application ratio = actual irrigation application/theoretical irrigation requirement

Figure 25 shows a histogram of the application ratios for the homes in Albuquerque. The x-axis on the graph represents the application ratio at the top of a range. The data under the bins represent the percent of the logging homes that fall into the individual bin, and the cumulative percent that fall into all bins equal to or less than the bin.

For example, the first bin in the figure, labeled 25%, represents the homes in which the calculated application is between 0% and 25% of the TIR. The figure shows that 46% of the homes in the Logging Group fell into this bin. The second bin, labeled 50% shows that 17% of the study homes were applying from 25% to 50% of the TIR and that a total of 63% of the homes were applying 50% or less of the TIR. The fourth bin shows that a total of 84% of the homes were applying at or below the TIR, which implies that only 16% of the homes in the study group were applying more than the TIR.

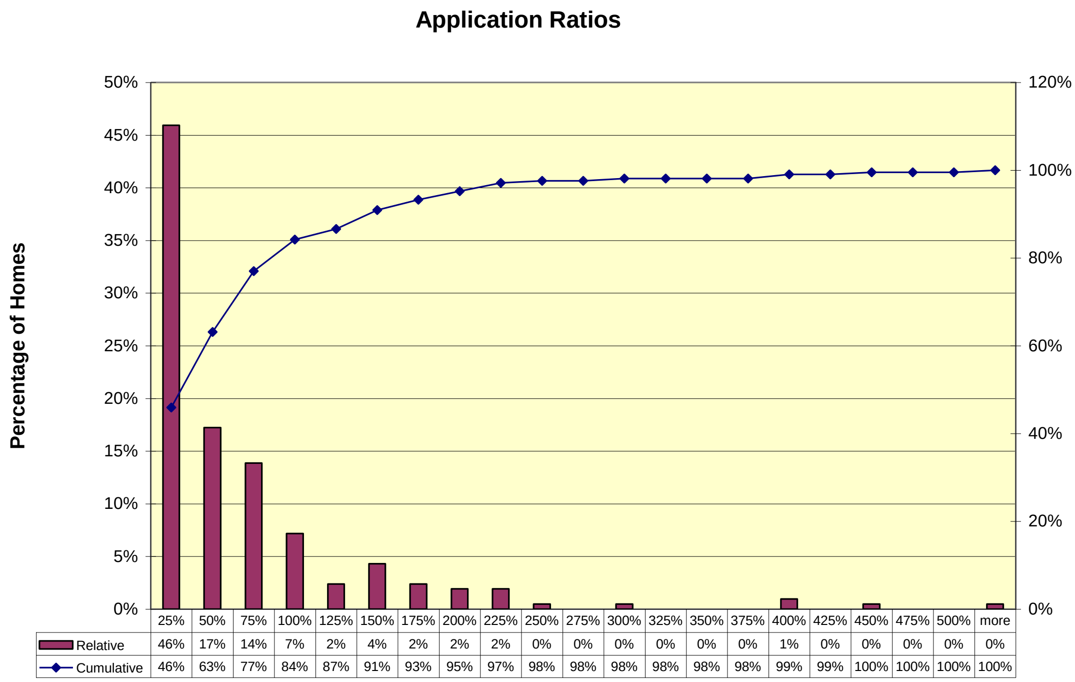


Figure 25: Application ratio histogram

Tables of ratios can be misleading since small lots may have a high application ratio, but they use only a small amount of water. On the other hand large lots may be deficit irrigating and have low application ratios, but use very large amounts of water. A more informative way of looking at the irrigation use is to determine the excess water use on all lots using more than their theoretical requirement. Lots that use less than their requirement have an excess of zero. The average excess use is the average for all lots in the study group. It tells the potential water savings per customer if excess use is eliminated, and deficit irrigation is left untouched.

When the excess use data for the Logging Group are analyzed the results are as shown in Table 34. This shows that 33 out of the 209 homes (16%) in the study group were applying more than their theoretical requirement. The total excess for the 209 customers amounted to 1,141 kgal. The average excess irrigation use was 5.5 kgal per lot for the 209 study homes, and 34.6 kgal for the 33 homes that were over irrigating.

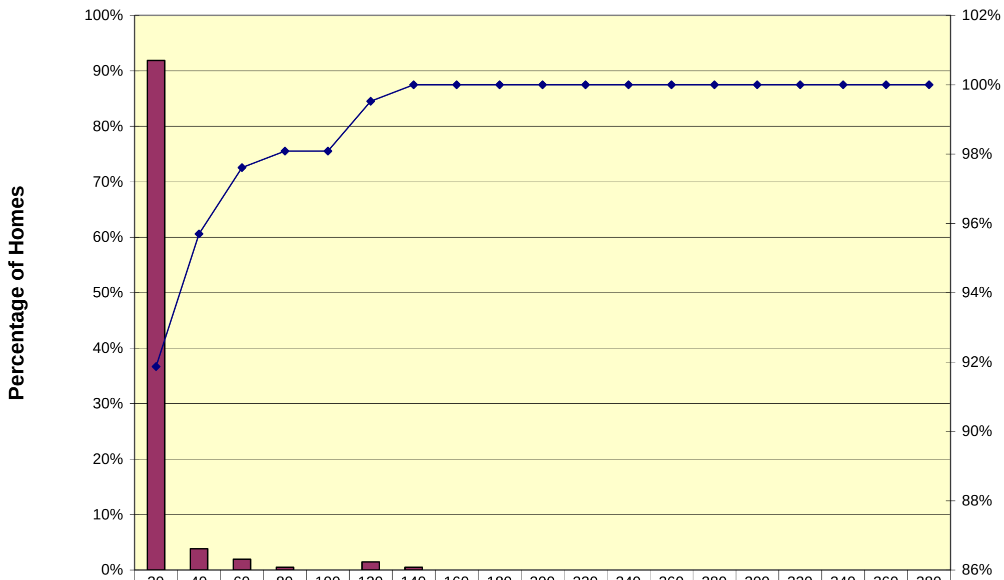
The data in Table 34 show that 16% of the customers in the study group accounted for all of the excess irrigation use. From the perspective of the population the results indicate a potential savings from elimination of excess irrigation of 5.5 kgal per customer, but from a practical perspective these savings will only be found on a small group of homes (16% of the total) on which actual excess use is over 34 kgal. This suggests that a carefully targeted program of irrigation conservation offers the most promise of success, while one aimed at the general population will have little effect, or may have the opposite effect from the intended one.

Table 34: Excess application (kgal)

Excess Application (kgal)	
Mean for all sites	5.5
Mean for over-irrigators	34.6
Median	0.0
Sum	1141
Count	33 out of 209
Confidence Level (95.0%)	2.45

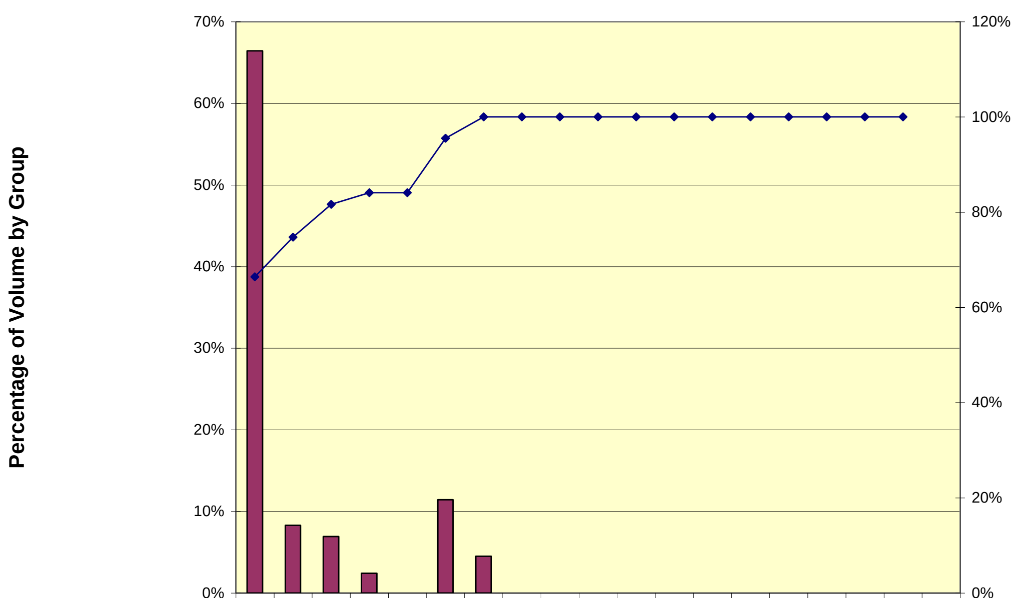
The distribution of excess irrigation in the customers is shown in Figure 26. This figure shows that 92% of all customers are applying between 0 and 20 kgal per year too much water to their landscape. The remaining 8% of customers are applying from 20 kgal to 140 kgal per year in excess.

As shown in Figure 27, the 8% of customers that are applying more than 20 kgal in excess of their annual requirements account for 34% of the total volume of excess use in the system. This implies that if these customers could be located the City could eliminate 34% of its excess single family irrigation use and have to deal with only 8% of its single family customers.



	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380
Relative	91.9	3.8%	1.9%	0.5%	0.0%	1.4%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cum %	92%	96%	98%	98%	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 26: Distribution of excess use by percent of homes



	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380
% of excess volume by group	66.4%	8.3%	6.9%	2.4%	0.0%	11.4%	4.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
Cum %	66%	75%	82%	84%	84%	96%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

Figure 27: Distribution of excess use by percent of volume

Discussion of Outdoor Use and Combined Potential Savings

The results of the outdoor analysis show that there was a total of 1,141 kgal of excess water use during the study year in the 209 study homes. This averages approximately 5.5 kgal per home. One thing we know is that this is not typical of the single family homes in Albuquerque because the Logging Group was intentionally chosen from only the higher use group, those averaging 105 kgal of use per year. Judging from Table 3, only around 25%, or 40,000, of the customers use 105 kgal per year or more. If an average savings of 5.5 kgal could be achieved in the 40,000 homes using more than 105 kgal per year then the total potential savings from elimination of excess irrigation in the Albuquerque system would be 220 MG, or 675 AF per year. As shown in Figure 27 more than half of these savings will be found on around 3200 lots, which represent 8% of the 40,000 target single family group.

This discussion of outdoor savings potential is an illustration of how the detailed data collected as part of this study can be used for water demand planning. It assumes only that excess irrigation use can be eliminated on the lots on which there is currently over-irrigation taking place, and that this can be done in a manner that does not cause other customers who are currently not over-irrigating to increase their water use. It also does not include the effects of either reducing irrigated areas or changing plant types to lower water using varieties. Employing either of these methods would increase the outdoor savings potential.

The discussion of the indoor water use above gave an estimate of around 1900 MG of savings from upgrades to indoor water use, which is almost 9 times the estimated outdoor savings. The reason for this is the much larger group of homes that are included in the potential indoor upgrade group. The entire population of single family homes has very similar indoor use patterns. Consequently, all or most of the 151,978 customers are part of the indoor conservation target group, while only 40,000 accounts are potential targets for the outdoor measures, i.e. those customers using 105 kgal/year or more. This suggests that over time indoor conservation is probably a more promising approach for Albuquerque than outdoor programs. Figure 28 shows the projected savings for the indoor and outdoor water use graphically. The remainder of this report discusses the actual savings that were measured as part of the retrofit study, which will help shed more light on these estimates.

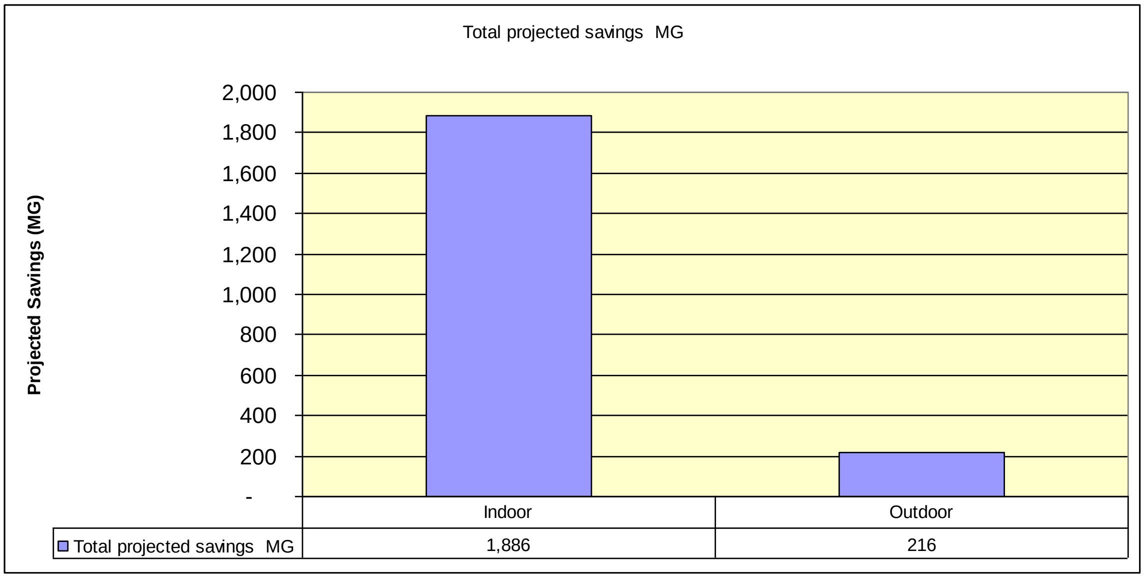


Figure 28: Projected water savings for Albuquerque single family accounts

The Retrofit Program

In order to get a better estimate of the potential for interior retrofits to reduce single family water use a group of 90 high water users was selected as potential participants in the retrofit phase of the project. This group was selected from the 240 study homes whose water use was tracked in the summer and fall of 2010. Careful attention was paid to the distribution of homes throughout the Water Authority service area. These homes received an "Agreement to Participate in the Albuquerque Single Family Retrofit Study" letter stating they were selected as a candidate to receive an in-home inspection, and possible inclusion in the final retrofit group. The letter gave the customer a brief description of the project, described Aquacraft's role as contracted through Water Authority to obtain information on water use patterns in the home, and described in detail what to expect during the in-home inspection and final retrofit. They were informed that 30 of the homes that consented to an in-home inspection of existing appliances and fixtures would be randomly selected to participate in the retrofit portion of the study. Forty homes signed and returned the Agreement.

In-Home Inspections

After the preliminary selection of the retrofit group the homes were visited in order to verify that they were good candidates. In-home inspections of appliances and fixtures were performed at 40 Albuquerque homes. The “Agreement to Participate” was verbally reviewed with the customer to ensure that the terms of the agreement were understood. Each customer went over general project information and the specific details of their involvement in the retrofit phase. This included information about the in-home inspection that was about to take place, the availability of options in selecting devices or appliances to be installed, costs covered by Aquacraft and potential costs to the customer, contractor information, and an explanation of expectations for the rest of the project period. Each homeowner was asked a series of questions to verify the count of existing appliances and devices in the home. They were also asked how many people were living in the home during the 2010 logging period and how many people would be living in the home during the 2011 logging period. Although this information had already been obtained from the survey mailed to the customer in the spring of 2010, it was important to make sure they understood how to answer the question correctly.

To begin the inspection, each existing water-using fixture or device was examined, measured, and photographed. For each toilet and washing machine the space available was recorded as measurements of depth, width, and height. The flow rate of each fixture was recorded using gpm markings as verified with flow bags. The make and model of all toilets and appliances were recorded when available. The irrigation controller was examined and photographed. Controller settings, watering zones, plant types, and leaks were discussed. Each customer was questioned on potential sources of leaks in their home both indoors and outdoors. Water softeners and reverse osmosis systems were identified and photographed.

Final Home Selection

After the in-home inspection was complete, 31 good candidates were selected for the final retrofit group. Thirty-one homes were selected so that if one of the homes decided drop out of the study, there would still be a group of thirty homes for the retrofit. Homes were selected to maximize savings. If the home was already equipped with high efficiency devices it was dropped from the retrofit group. Thirty-one high water users with homes that had not been recently remodeled with high efficiency devices were selected to receive the retrofit. A meeting was scheduled with homeowners to review the final list of devices to be installed. Each homeowner received a packet of information with specification sheets for each appliance or device to be installed and ways to save water around the home.

Two homes dropped out of the study after the final pre-installation meeting. One home had other pressing issues to deal with and did not want to go through with the installation. The second home needed to repair their toilet and washer immediately because they were not working properly and did not want to wait for the installation. They were also concerned that toilet that would be installed would be too low to comfortably sit down because they had knee problems. Although an ADA model was available the homeowner was not satisfied. The final retrofit group consisted of 29 homes.

Description of Devices Used

To ensure the highest attainable efficiency benchmark for Albuquerque homes, careful consideration was given to the fixtures and appliances used in the retrofits. Various specifications were developed for the selection of the fixtures and appliances. For each appliance or device customers were presented with several options to best suit their needs.

Toilets

Toilets supplied were required to meet the WaterSense® efficiency and performance criteria for high-efficiency toilets (HETs) and achieve a Maximum Performance (MaP) flush performance of 400 grams or greater[12].

Toilets supplied had an average flush volume of 1.28 gallons and may be:

- Single flush ≤ 1.28 gpf or dual flush (≤ 1.6 gpf/≤ 0.8 gpf)
- Gravity-fed, pressure or power assist, gravity-fed with vacuum assist
- One or two piece design

12 Gauley, W. & Koeller, J., 2010. Maximum Performance (MaP) Testing of Popular Toilet Models, A Cooperative Canadian and American Project, Mississauga, Ontario & Yorba Linda, California.

Dual flush and single flush toilets were selected so that approximately 50% of the homes would receive dual flush toilets and 50% would receive single flush toilets. Although different toilets would be installed in different homes, the type of toilet would be consistent throughout each household. A dual flush toilet and a single flush toilet would not be installed in the same home. The space available measurements were used to verify that the dual flush or single flush toilet would fit in the space available in the bathroom. Examples of the dual flush and single flush toilets installed in the homes are shown in Figure 29. All toilets in the study were provided by Kohler Company at no cost.

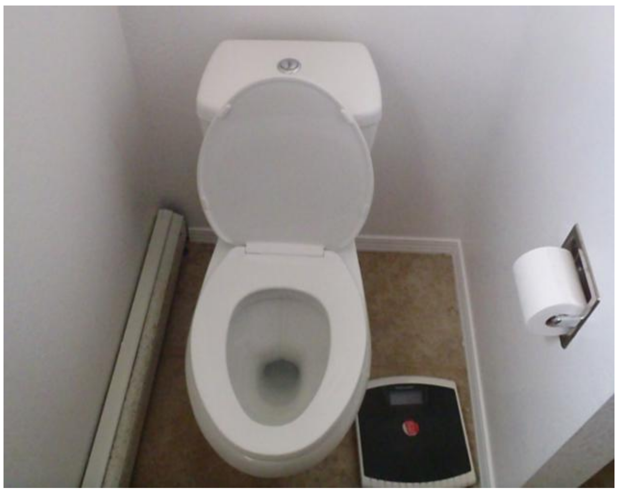


Figure 29: Dual flush toilet (left) and single flush toilet

Showerheads

Showerheads were required to be a WaterSense® labeled product[13] with a flow rate no greater than 2.0 gpm and no less than 1.75 gpm. Handheld and standard showerheads were made available as a choice to homeowners. Figure 30 shows both the handheld and standard showerheads that were installed in the retrofit homes. Showers were donated by the Kohler Company.

13 USEPA WaterSense began labeling of showerheads in March 2010.

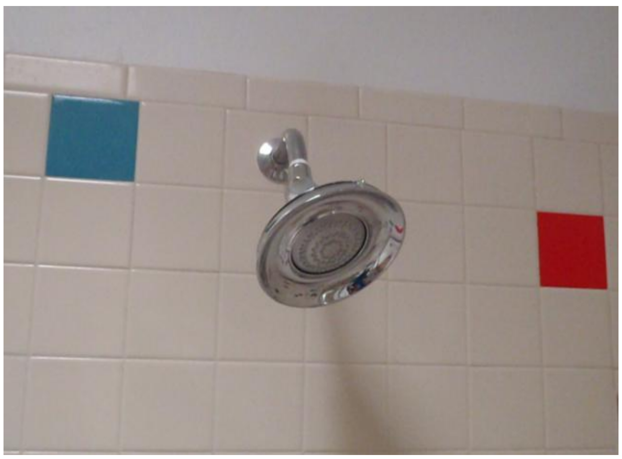


Figure 30: Handheld showerhead (left) and standard showerhead

Clothes Washer

Clothes washers supplied were required to be on the current Consortium for Energy Efficiency (CEE) Residential Clothes Washer Qualifying Product List[14]. All models were required to meet the CEE Tier 3 level, have a Water Factor (WF) ≤ 4.5 AND a Modified Energy Factor (MEF) ≥ 2.2 (from the 2007 edition of the list[15]). Homeowners were asked to select either a top loader or a front loader. The space available measurements made during the in-home inspections were used to verify that the top loader or front loader that was selected would fit in their laundry room or area. If the homeowner had recently purchased a high efficiency washer, or if the trace data for that home

14 CEE, 2011. Super Efficient Home Appliances Initiative. Clothes Washer Qualifying Product List.

15 CEE, 2007. Super Efficient Home Appliances Initiative. Clothes Washers. Market Information.

indicated that the washer used less than 22 gallons per load, the washer in that home was not replaced. High efficiency washers *typically* use less than 22 gallons per load, and several homes were already using between 15 and 17 gallons per load. An example of a front loading and a top loading clothes washer is shown in Figure 31.

Figure 31: Front loading clothes washer (left) and top loading clothes washer

Faucets/Aerators

Faucets and aerators were selected to meet flow rate and device shutoff requirements. Kitchen faucets were selected with a maximum flow rate of 2.2 gpm and lavatory faucets with a maximum flow rate of 1.0 gpm.

All faucets were required to have a shut-off device in addition to or as a replacement for shut-off at the handles. Such devices may have included but were not limited to:

- Hands-free faucets, for the kitchen and bathroom sinks, such as:
  - Infrared sensor
  - Foot-pedal operated
- One-touch devices
  - Tap on/off

- Flip lever on/off (aerator has a lever that allows flow to be controlled without touching handles)
- Push and flow aerators (aerator has an activation device that starts the flow of water)

For the kitchen sink the customer was asked to choose between a “one touch” faucet, faucet aerator, or foot pedal system. The existing faucet was examined to determine which options were best suited for the type of faucet in place. The foot pedal system was not a popular choice; only one home selected this device initially and then opted not to install this option. The “one touch” faucet was the first choice for many homeowners unless they had recently remodeled their sink and did not want to make any changes. Examples of the two most commonly installed faucet devices are shown in Figure 32. Many homeowners were intrigued with the Push-n-Flow bathroom aerator. Some homes opted out of the Push-n-Flow aerator because hot water was slow to reach their lavatory faucets. In some cases they let the water run in the bathroom for minutes before it warmed up enough for use. Examples of the most commonly installed lavatory faucet devices are shown in Figure 33.


Figure 32: Kitchen One Touch faucet (left) and kitchen flip lever

Figure 33: Lavatory flip lever aerator (left) and Push n Flow aerator

Irrigation Controllers

The initial retrofit plan included the installation of smart irrigation controllers. After the landscape water use analysis was complete it was determined that only three homes in the retrofit group were over-watering. Many customers were already “Watering by the Numbers” or had large portions of their property that were not being watered at all. Retrofitting only three controllers would not provide statistically significant data. Smart irrigation controllers were dropped from the list of retrofit items to be installed.

The smart irrigation controllers would have to have been approved by Smart Water Application Technologies (SWAT). The controller would be a stand-alone unit or an add-on device that provides irrigation in response to local weather conditions. An interrupt device such as a rain sensor or soil moisture sensor must be installed on each controller. Controllers should not require homeowner to pay a subscription fee to receive weather data. Other requirements of the controller include:

- Cycle and soak capability
- Default irrigation mode in the event of power failure
- Minimum eight zone capacity
- Multiple schedules
- Back-up power source in the event of failure of the primary power source

Master Valves

The initial retrofit plan included the installation of master valves to prevent leaking in the irrigation system. The master valves were also dropped from the list of retrofit items to be installed because the landscape analysis showed that only three homes out of the 29 were over-watering. If it had been included in the home retrofit, the brass master valve would have been designed to prevent leakage of any zone in the irrigation system in the event of a solenoid failure. Important design features of the master valve would have included:

- The master valve should be designed such that the valve remains closed in the event of a diaphragm wall failure
- Compatibility with the low flows of micro-irrigation
- Corrosion protection
- Ability to reduce flow rate during closing to minimize water hammer

Final Retrofit List

The final list of items to be installed in each home was determined using information from the in-home inspections and from input from the homeowners.

Table 35: Summary of total high efficiency devices and appliances installed in the 29 retrofit homes

Keycode	Clothes Washer	Kitchen Faucet	Toilets	Showerheads	Bathroom Aerators
10S404	1	1	3	2	5
10S407	0	1	2	2	3
10S409	1	1	2	2	2
10S414	1	1	2	2	2
10S416	1	1	2	2	2
10S417	1	0	3	3	0
10S421	1	1	2	2	2
10S424	0	1	2	2	3
10S425	1	1	1	1	1

Keycode	Clothes Washer	Kitchen Faucet	Toilets	Showerheads	Bathroom Aerators
10S429	1	1	2	2	2
10S430	1	1	2	2	4
10S435	0	1	3	2	5
10S439	1	1	2	2	2
10S440	1	1	2	2	2
10S442	1	1	3	2	4
10S444	1	1	2	2	2
10S448	0	1	3	2	3
10S450	0	0	3	3	5
10S461	1	1	2	2	2
10S465	1	1	2	2	3
10S469	1	1	2	2	0
10S475	0	1	3	3	2
10S477	1	1	3	2	4
10S479	0	1	3	2	3
10S492	0	2	2	2	2
10S497	1	1	2	2	3
10S502	1	1	2	2	2
10S504	1	1	2	2	2
10S509	1	1	2	2	2
TOTAL	**21**	**28**	**66**	**60**	**74**

Costs for Retrofit Program

The retrofit program used for this study was the most expensive type that could be designed from the perspective of the sponsoring water agency. All of the costs for the program were born by the agency, and none of the direct costs were born by the customer. The reason that this model was used was that the goal of the study was not to perform a cost-effectiveness analysis, but to conduct a research project on the water conservation potential of the new fixtures and appliances in the study homes. The agency was paying for the program in order to obtain information on the effectiveness of the retrofit devices for reducing water use. The water saving information could then be used in combination with the marginal value of water to examine cost effectiveness of future programs.

Because the program was basically a research effort a disproportionate amount of the expenditures went into program administration, design, planning, purchasing and evaluation. Another complicating factor was that all of the toilets and showerheads were donated to the project by the Kohler Company. Hence, it is necessary to adjust the gross project costs to include the value of these two key devices.

Table 36 shows a summary of the costs attributed to this retrofit study. This table shows the actual costs paid by the ABCWUA for the retrofit project with the exception of costs for Task 3, the Retrofit. These have been adjusted to include the estimated value for the 66 donated toilets and 60 donated showerheads. Average values of $250 per toilet and $25 per shower head were used to make the adjustments. By adding these values onto the cost of the project the total costs were adjusted to represent what they would actually have been without the donations. The total adjusted cost for the study was $432,035. This included all planning, consulting, data collection and analysis, plus purchase and installation of devices.

Table 36: Summary of Program Adjusted Costs

Task No.	Task Name	Total	Number	Unit Cost	Description
1	Baseline Water Use: 2009	$ 59,450.00	151,987	$ 0.39	Analysis of baseline water use from billing data
2	Baseline Data Logging	$160,077.00	209	$ 765.92	Sample selection, surveys, landscape analysis, home visits, data logging, analysis, report.
3	Retrofit and Analysis (adjusted for value of donated toilets and	$158,924.00	29	$ 5,480.14	Selection and purchase of products, final home inspections, installation, data logging, analysis and reporting

	showerheads)				
4	Evaluation of Impacts and Report	$ 49,377.00	29	$ 1,702.66	Final statistical analysis and preparation of report
5	NM Sales Tax	$ 4,207.00	29	$ 145.07	Tax paid for consulting services
	Adjusted Totals	$432,035.00	29	$ 8,094.17	Total adjusted cost

Table 36 shows the total costs for the tasks and the estimated unit costs based on the number of homes involved in each task. The least expensive unit cost was Task 1, the Baseline Water Use, which cost $.39 per home when based on the total number of single family residences in the system. Task 2, the Baseline Data Logging Task cost approximately $766 per data-logged home. The most expensive task on a unit cost basis was the Retrofits, which cost nearly $5500 per home for the 29 homes in the study. This included all of the work done in planning and performing the retrofits, plus the costs for the post-retrofit data logging and analysis.

Not all of the tasks shown in Table 36 are proportional to the size of the study, so as more homes are included in future application programs the planning and evaluation costs will not rise proportionally. This study has established a set of baseline water use conditions, based on 2009-2010 conditions. In future studies the emphasis would be on Evaluation of Impacts, which would include sampling, data logging and analysis of samples of test homes that had participated in future residential conservation programs. The cost of these studies would be proportional to the size of the sample required to obtain accurate measurements of water use, not the number of homes included in the program itself. For example, if the ABCWUA were to set up a residential retrofit program that included 10,000 homes, the same sample size, of around 200 homes would be sufficient to analyze the impacts. Even if the entire single family population was upgraded the required sample would not be more than twice that used here. So, in this case the total cost for an evaluation study would around $250,000 but the unit cost, would be divided by the size of the population, or approximately $1.64/home.

The costs of any conservation program will be based on its scope and timing. If a very aggressive program were chosen, which relied heavily on rebates and actions by the ABCWUA, then the costs would be higher, but if a more passive program, relying on building codes, upgrades on sale and rate based incentives were used the direct costs to the agency would be much lower. The decision as to which route to choose is one that would be made by the agency based on the situation it finds itself in at the time, and how critical it finds water conservation to be, and on how high a value is placed on the saved water.

Post-retrofit Water Use

The retrofits that were performed on the 29 homes of the Retrofit Group were directed at indoor uses. As explained above, not enough of the homes in the Logging Group had sufficient excess irrigation use to warrant having an outdoor component to the study. Instead, it was focused on reducing indoor use to the extent possible. For comparison purposes the annual water use patterns of the retrofit group are shown along with those of the population and Logging Group in Table 37.

Notice that the annual water use of the Pre-Retrofit Group was significantly higher than that of either the population or the Logging Group. The reason for this is that the homes for the retrofit group were chosen from the top quartile of water users so that it would be possible to see the impacts of the retrofits on the largest water users. This makes sense, since presumably future conservation programs would likely be targeted to larger users.

Table 37: Comparison of annual use

Parameter	Population	Logging Group	Retrofit Group
Number	151,987	209	29
Average Annual Use	94.8 kgal	103.2 kgal	156.6 kgal
Average Seasonal Use	31.7 kgal	37.6 kgal	68.8 kgal
Average Non-Seasonal Use	63.0 kgal	65.6 kgal	88.1 kgal

When making estimates of potential water savings from the retrofits, it is important to keep in mind that the savings will be proportional to the starting water use of the group to which they are applied. The larger the starting water use, the larger will be the savings. On the other hand, there are fewer large water users, so while the unit savings will be greater the total savings to the system may be greater when aimed at larger populations.

Since this study ended up focusing on indoor measures the most appropriate parameter for comparison is the non-seasonal water use, which is the best proxy for indoor use available from billing data. From Table 37 it can be seen that the non-seasonal water use of the Logging Group was quite similar to that of the population. So, when making projections of indoor savings the use of the Logging Group as a starting point is the most accurate method. In most of the comparisons shown below the post retrofit water use will be compared to that of the Logging Group, in order to show what is believed to be the best representation of how the retrofit program would impact the general population of the Water Authority, but comparisons to water use by quartile also have a value, as will be seen.

Total Indoor Use

The data showed that the retrofits resulted in a significant decrease in the indoor water use. The average indoor use for the Pre-Retrofit Group is shown in comparison to the Logging Group and the REUWS group in Table 38. These data are taken from the data logging results and are direct measurements of indoor use; not estimates from billing data. The average indoor use of Albuquerque Logging Group was 138 gpd. The average indoor use of the Pre-Retrofit Group was 174 gpd which was similar to the average of 177 gpd for the REUWS group. The Post-Retrofit daily average use, however, was 101 gpd, which places it within the most efficient use range. This implies a reduction of 27% in indoor use relative to the entire logging group and 42% relative to the retrofit group's baseline use.

Table 38: Average indoor use comparison from data logging

Parameter	REUWS (gpd)	Albuquerque Logging Group (gpd)	Retrofit Group Pre-Retrofit (gpd)	Retrofit Group Post-Retrofit (gpd)
Mean ± 95% C.I.	177 ± 5.5	138 ± 15.6	174.3 ± 24.5	101 ± 16.0
Median	160	118.9	173.0	99
Std Deviation	96.8	114.7	67.2	44
N	1188	209	29	29

The distribution of average daily indoor use for the Post-Retrofit Group is compared to the Logging Group in Figure 34. This figure shows a marked shift in use towards the lower bins after the retrofit, and the largest percentage of use in this group is centered between 100 and 150 gpd.

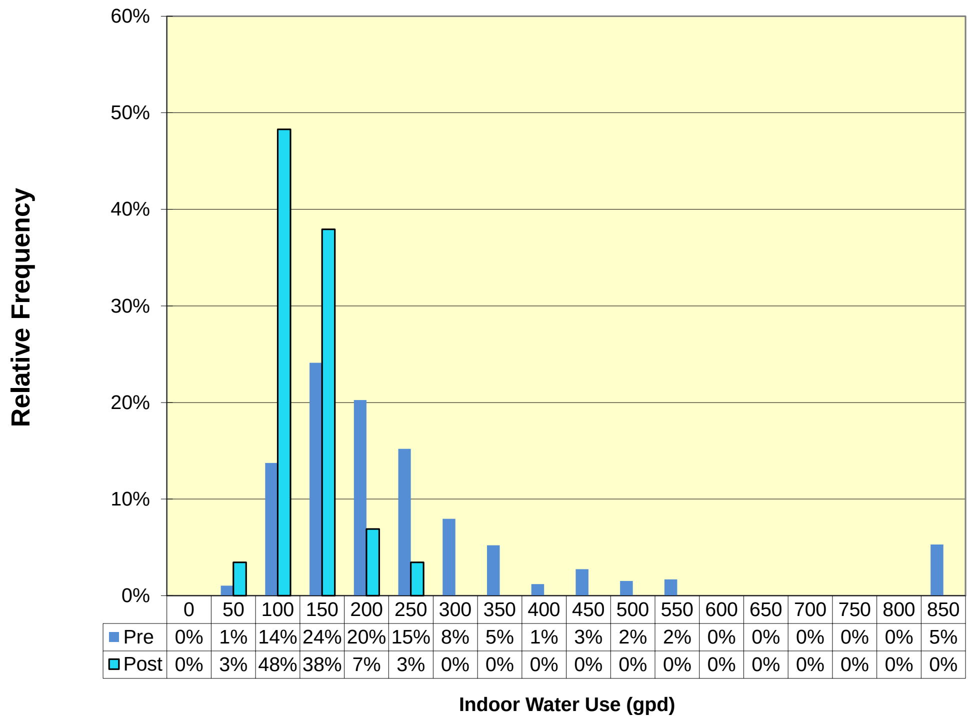


Figure 34: Comparison of pre and post daily indoor water use for Logging Group and Post-Retrofit Group

Comparison of Disaggregated End Uses

The breakdown of indoor uses for the Post-Retrofit Group is shown in Figure 35. As with the Logging Group it is seen that leaks, faucets, showers, clothes washers, and toilets make up the bulk of indoor use after the retrofit. As shown in Figure 35 these categories make up nearly 95% of total indoor water use in the Post-Retrofit Group.

A bar chart showing the pre and post household water use is shown in Figure 36. At a glance this chart shows that there were significant reductions in three categories of use: toilets, clothes washers and leaks. There was a small decrease in shower use, and faucet use actually increased a small amount. The other categories stayed largely the same. If one sums the end uses in the chart the total household water use post-retrofit comes to 101 gpd. The results for showers is somewhat misleading, since, as discussed in the section on showers, even though the gallons per shower and flow rates for the post retrofit showers was significantly lower than for the logging group, there were more showers per day in the retrofit homes, and this obscured the savings from the shower heads. The retrofit showers used approximately 25% less water than the baseline showers.

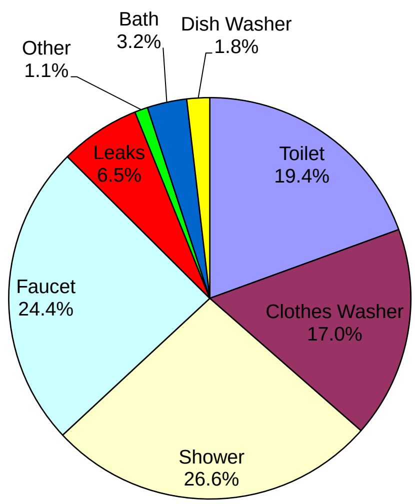


Figure 35: Indoor end use pie chart for Post-Retrofit Group

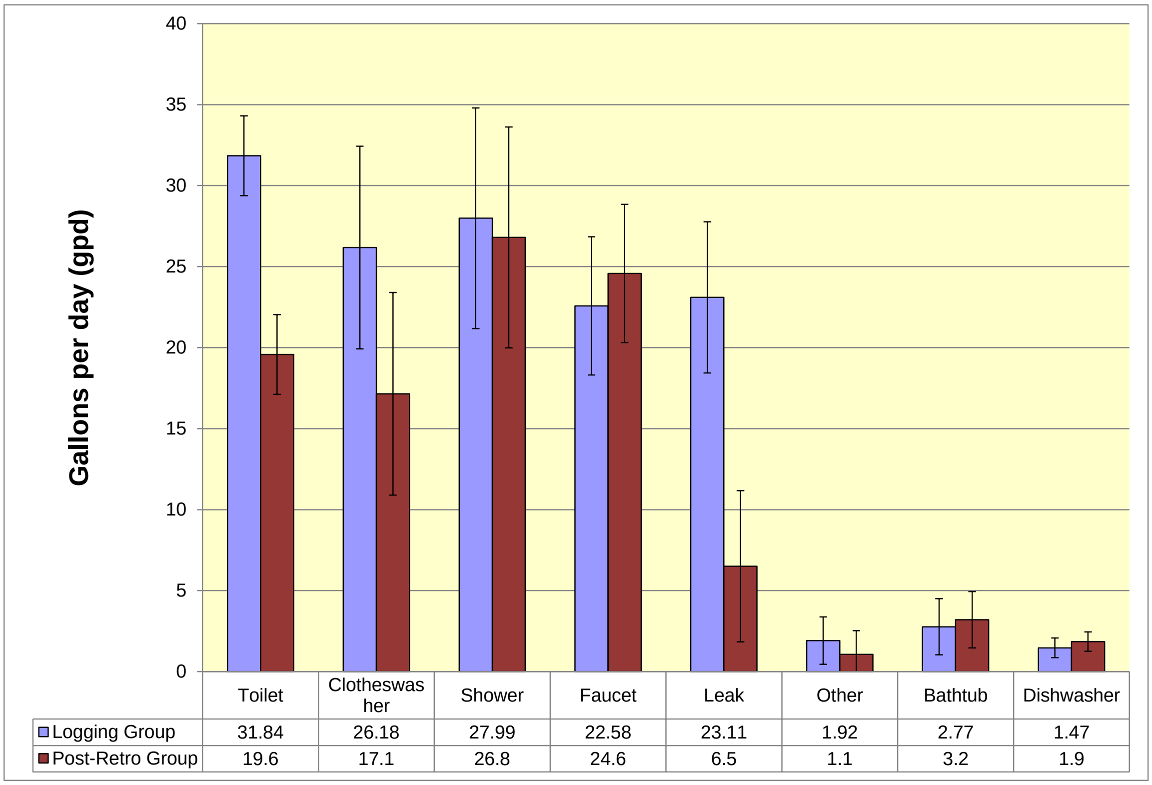


Figure 36: Comparison of the Logging Group and the Post-Retrofit Group

Toilet Use

There were a total of 5,075 separate toilet flushes recorded by the data loggers during the logging period of the Post-Retrofit Group. This is equivalent to 13.8 flushes per house per day over approximately 12.1 days of logging. The distribution of toilet flushes is fairly normal, as can be seen from the fact that the median and mean values are so close to each other. The statistics for individual toilet flushes are shown in Table 39. After the retrofits, ninety-seven percent of the homes had average flush volumes less than 2.0 gpf, which classifies them as high efficiency homes.

Table 39: Toilet use comparison

Parameter	Logging Group	Post-Retrofit Group
Total number of flushes in logging sample	33,449	5,075
Average flushes per household per day	12.7	13.8
Average toilet flush volume for all toilets(gal)	2.31	1.36
Median flush volume (gal)	2.54	1.32
% of homes with average flush volume < 2.0 gal	49.4%	97%

Figure 37 shows the distribution of pre and post household average flush volumes. Prior to the retrofit the homes contained a wide range of toilets, resulting in average flush volumes of up to 5 gallons or more. After the retrofits the largest average was at 2 gallons per flush. The post-retrofit distribution was closely centered around the 1.5 gpf bin, and 28% of the homes have average flush volumes between 1 and 1.3 gpf.

In analyzing the toilet data it was noted that the dual flush models achieved a slightly lower average flush volume. As shown in Table 40, the average flush volume in the dual flush equipped homes was 1.20 gpf, while the average in the standard flush homes was 1.46 gpf. Each home was equipped with either a standard or dual flush model, and the types were never mixed in the same home, so that this comparison would be easier to make.

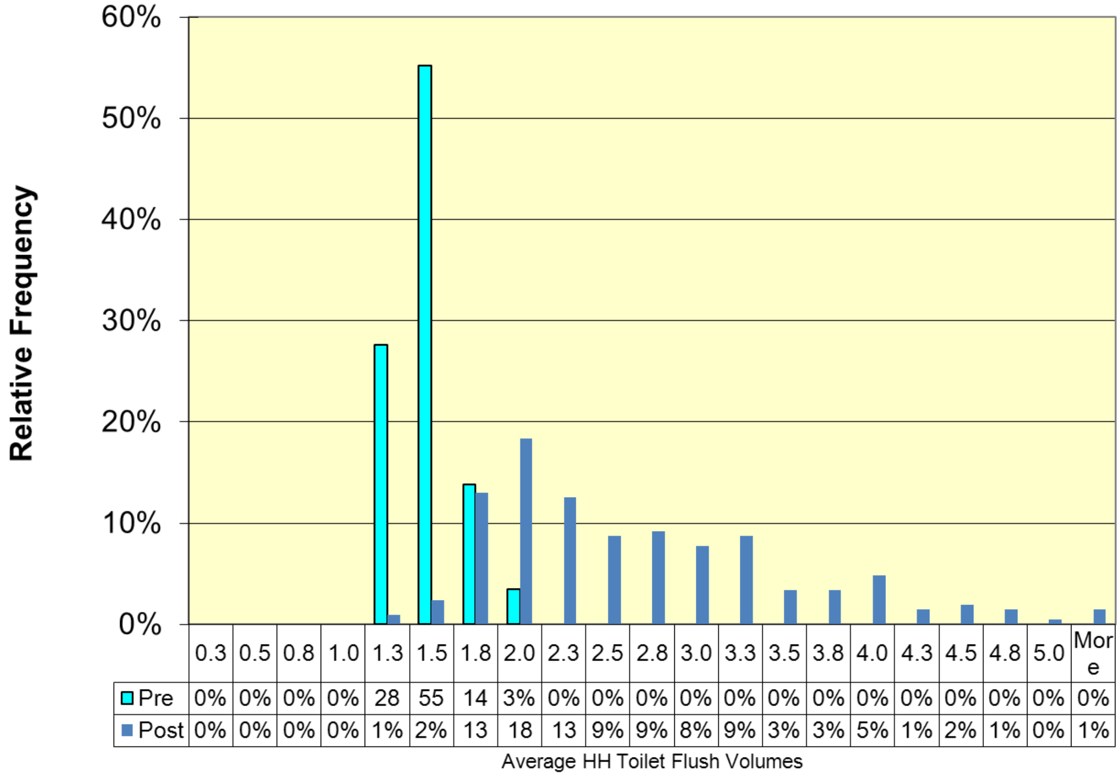


Figure 37: Comparison of household flush volumes between Logging Group and Post-Retrofit Group

Table 40: Comparison of single flush to dual flush toilets

Parameter	**Value**
Number of homes with single flush toilets	17
Average flush volume for single flush toilets	1.46 gpf
Number of homes with dual flush toilets	12
Average flush volumes for dual flush toilets	1.20 gpf

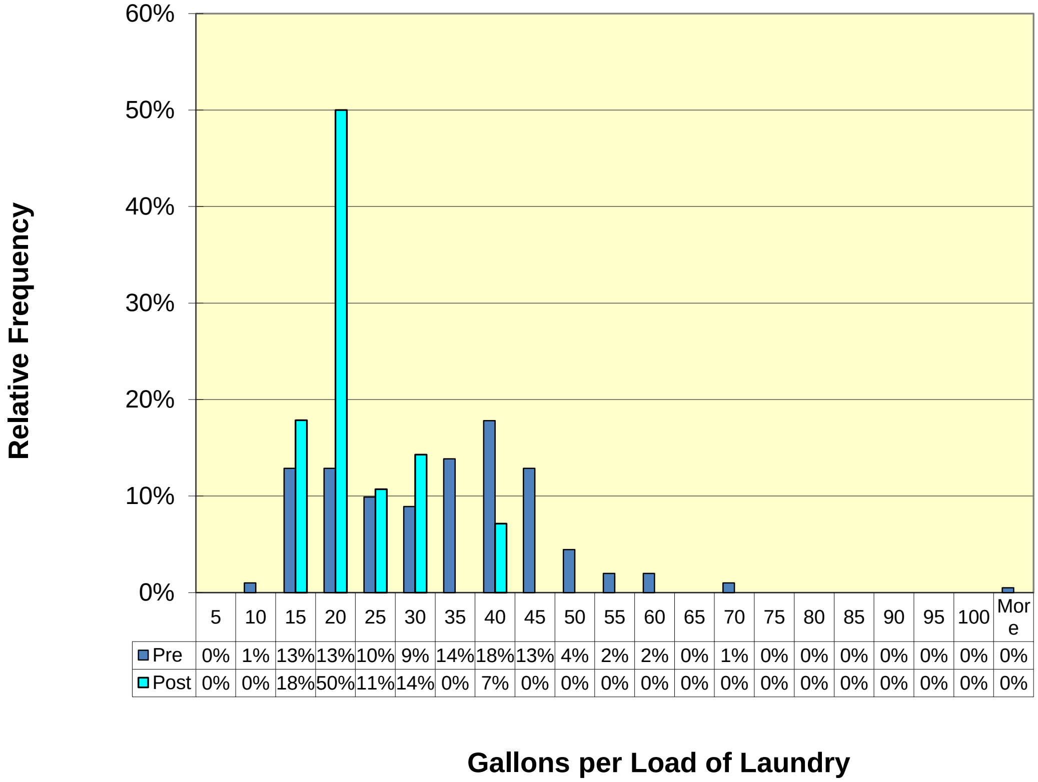
Clothes Washer Use

The statistics for clothes washers use is shown in Table 41 and the comparison of the distributions of average household load volumes is shown in Figure 38. During the logging period of the Post-Retrofit Group a total of 306 clothes washer loads were recorded by the data loggers on the 28 homes that had or used washers during the logging period. This averages to 0.9 loads per house per day over the 12.1 logged days per home in the sample. The median per load volume was 17.4 gpl and the average was 19.4 gpl which is a 39% reduction from the Pre-Retrofit Group. A total of 68% of the Post-Retrofit Group had clothes washer use of less than 20 gpl, which is compatible with CEE Tier 3 specifications, and 97% of the homes had average load volumes less than 30 gpl, which was the adopted criteria for high efficiency homes used for comparison urposes. Figure 38 gives a histogram of the average gallons per load in the pre and post conditions.

An interesting point observed in the analysis was that even though the clothes washers were rated as CEE Tier 3 machines, in actual use there were settings that could be selected that required much larger volumes of water. As shown in Figure 38 7% of the loads used between 35 and 40 gpl. Even with these large loads, the average use was still less than 20 gpl. The data from the logging study shows how the people actually used the machines in real life, which is more important for planning purposes than estimates based on design specifications.

Table 41: Clothes washer use data

Parameter	Logging Group	Post-Retrofit Group
Total number of loads in database	2,273	306
Average loads per household per day	0.9	0.9
Average gallons per load	31.7	19.4
Median gallons per load	31.9	17.4
% of houses with < 30 gpl	27%	93%



	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	More
Pre	0%	1%	13%	13%	10%	9%	14%	18%	13%	4%	2%	2%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Post	0%	0%	18%	50%	11%	14%	0%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 38: Comparison of distributions of clothes washer volumes of Logging Homes to Post Rerofit homes

Shower Use

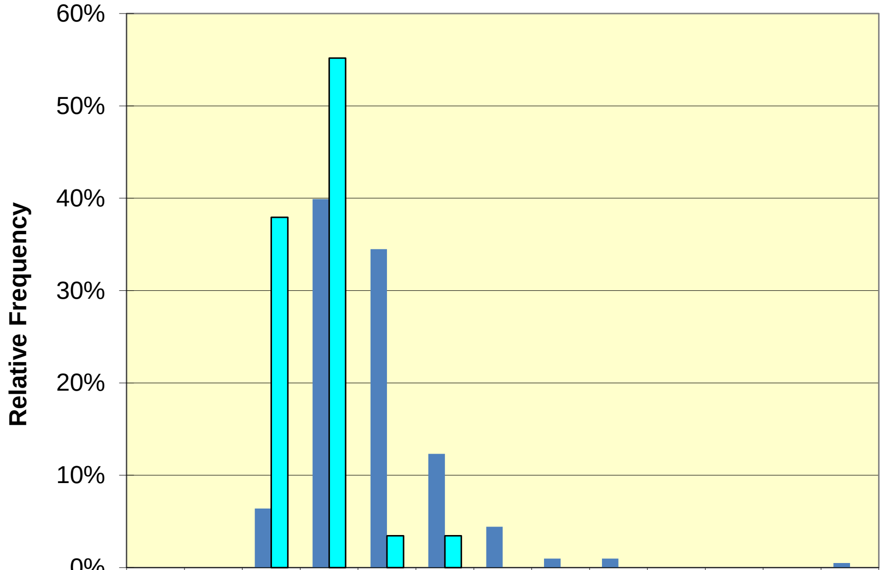
The shower use data are compared in Table 42. There were a total of 729 showers logged during the logging period of the Post-Retrofit Group. This averaged out to 2.1 showers per household per day which is slightly higher than the average of 1.8 from the Logging Group. The average shower used 12.5 gallons of water (25% less than the baseline showers), and the average shower flow rate was 1.6 gpm (27% less than the baseline). Approximately 93% of the post retrofit homes used less than 2.0 gpm for showers. Histograms of pre and post-retrofit flow rates and volumes are provided in Figure 39 and Figure 40 respectively. Shower volumes range from 7.5 gallons to 20 gallons. A comparison of shower durations is shown in Figure 41. Seventy-nine percent of the showers in the Pre-Retrofit Group were ten minutes or less in duration; in the Post-Retrofit Group 73% of the showers were ten minutes or less.

The key parameter in Table 42 is the gallons per shower value, which was 25% lower after the retrofit and before. The fact that the retrofit homes tended to have more showers per day than the logging group masked the savings from the shower heads. Also, the savings from the shower heads can be seen in the fact that both the average and median flow rates were significantly lower in the post retrofit showers, and the fact that 97% of all of the showers had flow rates that met the 2.5 gpm EPAct requirments, which values was only 46% prior to the retrofits.

Distributions of show flow rates, volumes and durations are shown in Figure 39, Figure 40 and Figure 41 respectively. Even though the changes are small, these figures all show a downward trend in each parameter. There are fewer high flow rates and high volumes. The durations are only very slightly lower in the maximum bins, but there are more events in the 10 and 12 minute bins.

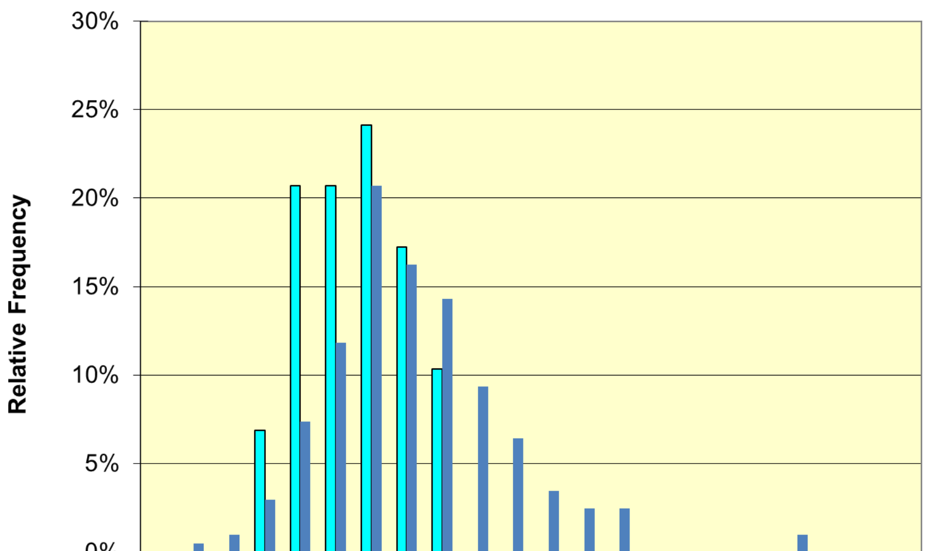
Table 42: Comparison of shower use data

Parameter	**Logging Group**	**Post-Retrofit Group**
Total number of showers in database	4,478	729
Average showers per household per day	1.8	2.1
Average gallons per shower	16.7	12.5
Average shower duration (min)	7.9 ± 0.36	8.2 ± 0.82
Average shower flow rate (gpm)	2.2	1.6
Median shower flow rate (gpm)	2.1	1.6
% of showers < 2.5 gpm	46%	97%



	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	More
Pre	0%	0%	6%	40%	34%	12%	4%	1%	1%	0%	0%	0%	0%
Post	0%	0%	38%	55%	3%	3%	0%	0%	0%	0%	0%	0%	0%

Figure 39: Comparison of shower flow rate distributions



	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	More
Post	0%	0%	0%	7%	21%	21%	24%	17%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Pre	0%	0%	1%	3%	7%	12%	21%	16%	14%	9%	6%	3%	2%	2%	0%	0%	0%	0%	1%	0%	0%	0%

Figure 40: Comparison of shower volumes

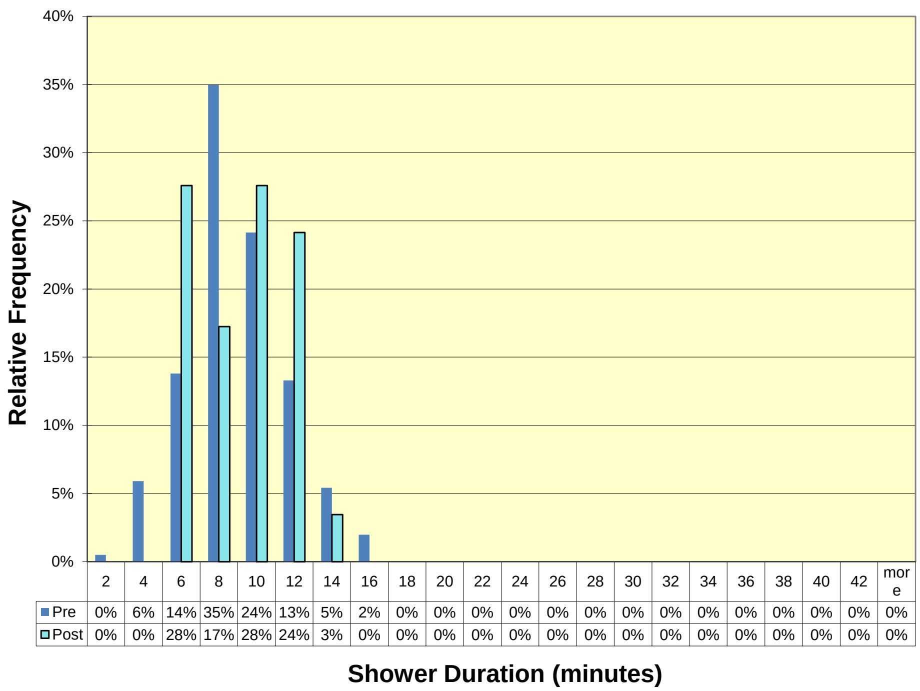


Figure 41: Comparison of shower durations

Leakage

There were no specific leak detection or prevention devices installed in the home, but the upgrading with new faucets and toilets certainly provided an opportunity for reducing leakage, and the post-retrofit data showed significantly lower leakage rates. The average leak rate in the Pre-Retrofit homes was 22.5 gpd, and this dropped to 7 gpd in the Post-Retrofit Group. The statistics on leaks are presented in Table 43, while the distribution of household leakage is shown in Figure 42.

Table 43: Leakage statistics comparison

Parameter	Logging Group	Post-Retrofit Group
Total number of days in database	2,649	352

Average leakage, gpd	22.5	7
Median leakage, gpd	1.7	2
Max leakage in set, gpd	974.8	61.6
% houses w/ leakage > 50 gpd	8%	3%
% houses w/ leakage > 100 gpd	4%	0%

The leakage data in Table 43 show that the average leakage rate was deceased by 70%, decreasing from 23 to 7 gpd, but that the median rate stayed essentially unchanged at 2 gpd. This means that a few homes with large leakage rates, such as the home with the maximum rate of 975 gpd, were repaired, which brought down the average for the group as a whole. A striking feature of the data is, as shown in Figure 42, prior to the retrofits there were homes in the bins ranging from 80 gphd to over 200 gphd of leakage, and after the retrofits the largest bin in which a home was found was the 70 gphd, which contained a single home. Likewise, as shown in Figure 43, the total volume of leakge accounted for in home with higher leakage was smaller as well.

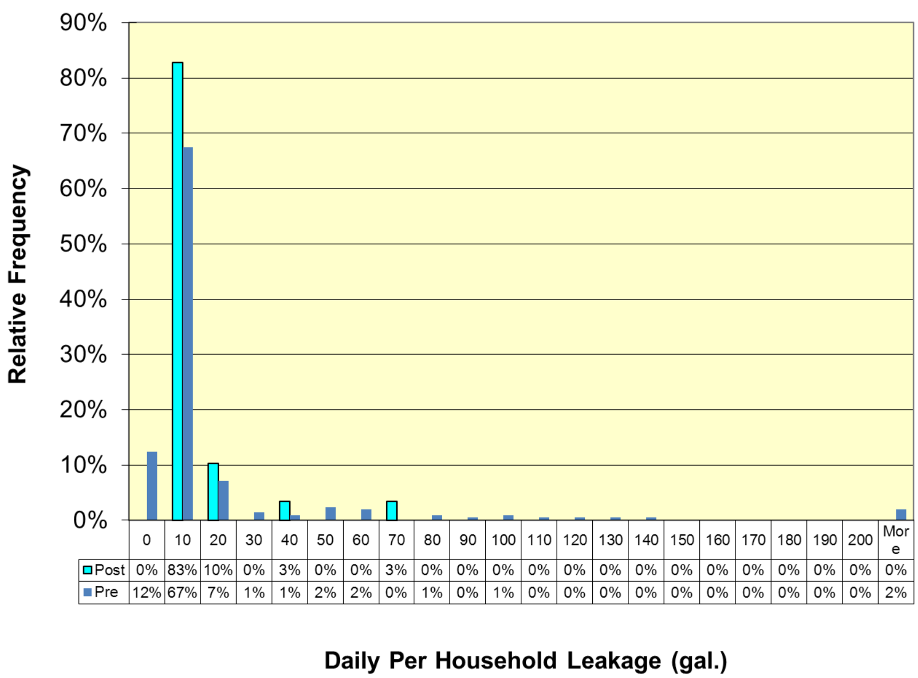


Figure 42: Percent of retrofit homes by leakage bin

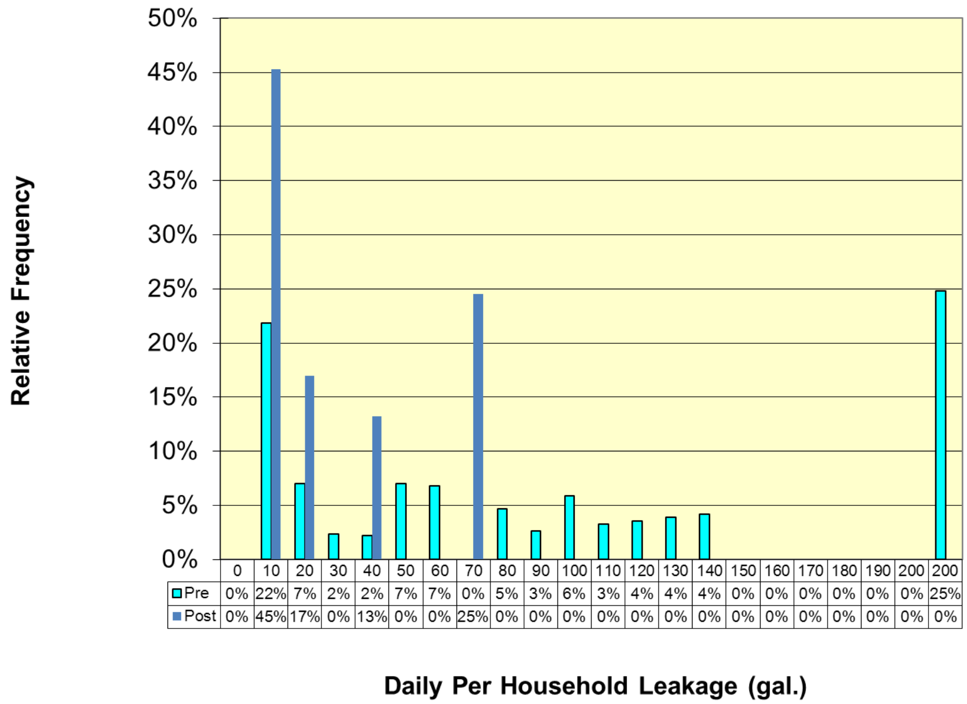


Figure 43: Percent of total leakage by leakage bins

Faucet Use

The faucet retrofits were intended to both reduce the flow rates of the faucet use and their duration. Figure 44 shows a comparison of the average daily household faucet use distributions between the Logging Group and the Post-Retrofit Group. Figure 45 shows a comparison of the percent of faucet events by flow rate, and Figure 46 shows a comparison of the percent of total faucet volume by the flow rate of the event. Despite all of these efforts, which included some expensive kitchen faucets, the average faucet use increased slightly in the Post-Retrofit Group rather than decreasing as was hoped. The average duration decreased slightly and there were fewer very large faucet events, but these reductions did not sway the use as a whole.

Table 44: Faucet use comparisons

Parameter	Logging Sample	Retrofit Homes
Total number of days in database	2,640	352
Average faucet use, gpd	22.7	24.6
Median faucet use, gpd	19.5	23.3
Average faucet duration (seconds)	34.6	31.5
Max faucet use in set, gpd	131	55.4
Number of faucet events	126,157	22,439

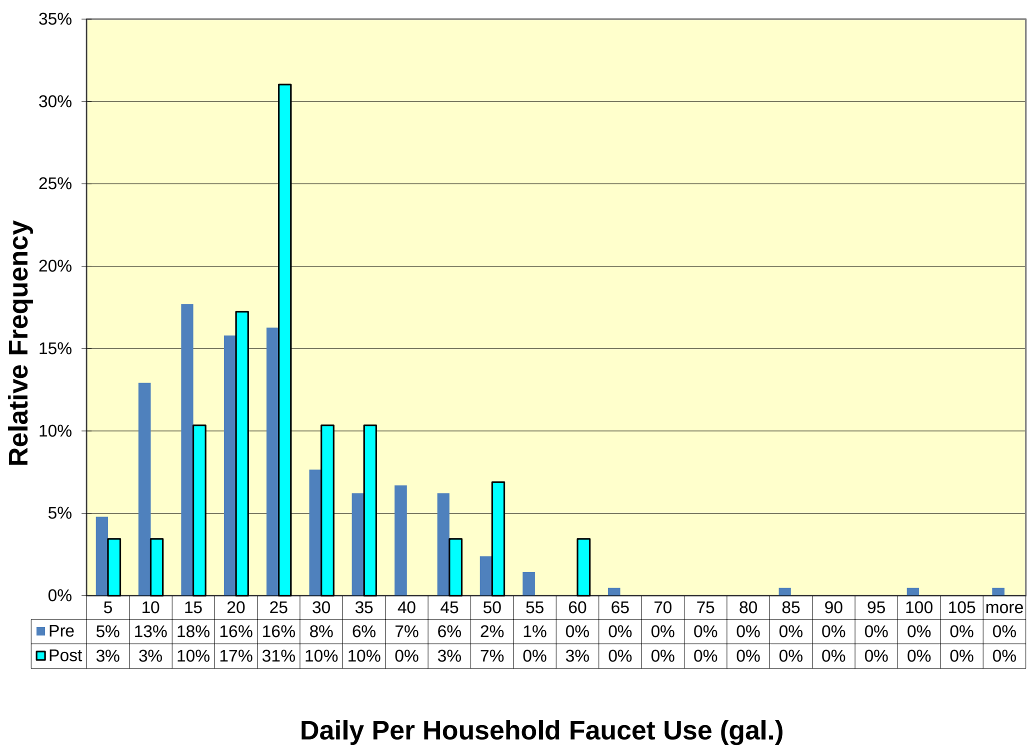


Figure 44: Comparisons of household daily faucet use

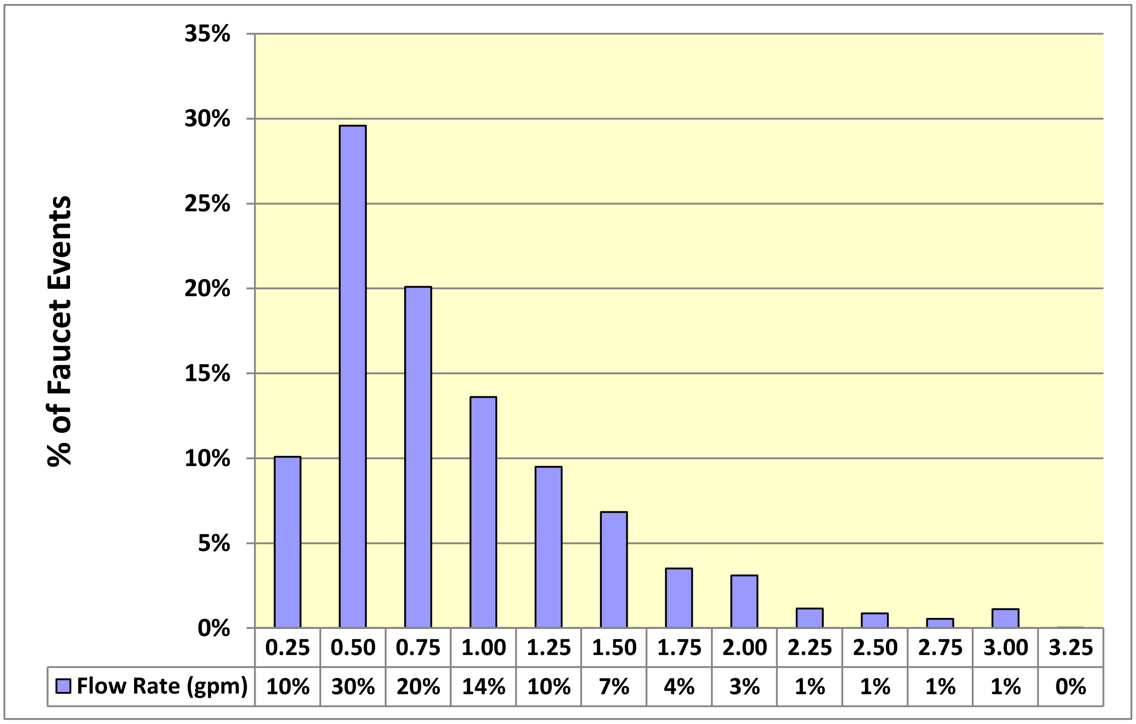


Figure 45: Percent of faucet events by flow rate, post-retrofit

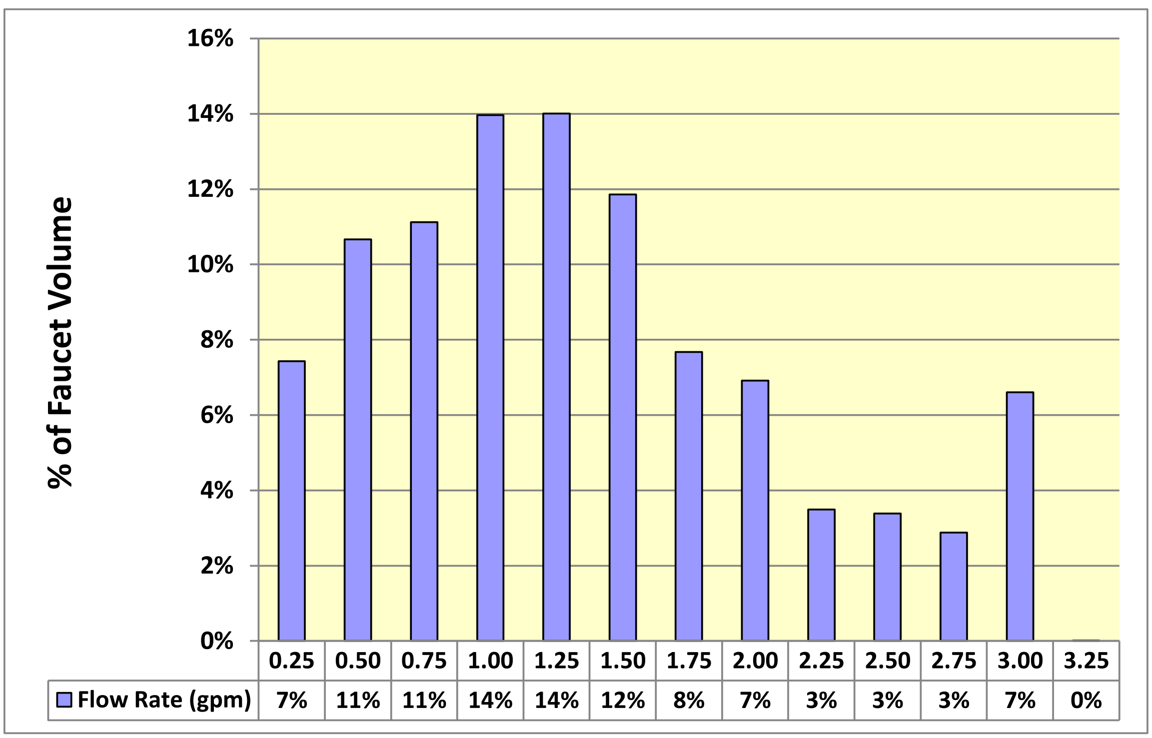


Figure 46: Percent of total faucet volumes by flow rate, post-retrofit

Per Capita Use Comparisons

When the total indoor water use is plotted against the number of persons in the home, a power curve results. The equation of this relationship, along with others for comparison, is shown in Table 45. The normalized household demands for a family of three are also shown in the last column of the table. The REUWS sample was found to use 187 gpd for a family of three, while the Albuquerque Logging Group used 146 gpd. The EPA Retrofit sample used 117 gpd, and the Albuquerque Post-Retrofit Group used the least, at 94 gphd, or 31.1 gpcd.

Table 45: Daily per capita use relationships with retrofit homes

Sample	**Relationship**	**Household Use for Family of Three**
REUWS	$y = 87.41\ x^{0.69}$	187
Logging Sample	$y = 67.26\ x^{0.70}$	146
EPA Retrofit	$y = 50.21\ x^{0.77}$	117
ABQ Post- Retrofit Homes	$y = 75.87\ x^{0.20}$	94

The curves for the equations are plotted in Figure 47. The Post-Retrofit Group has the lowest water use per home for all except for single occupant homes. Also, these homes show the least impact on household use as additional persons are added to the home. This may be an artifact of the small sample size, but it is still a significant finding.

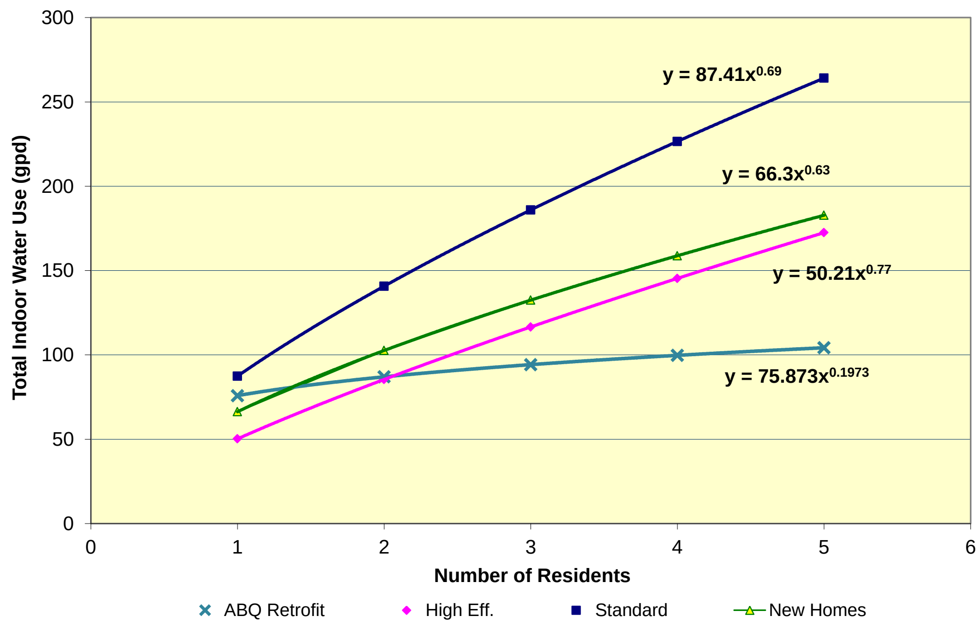


Figure 47: Comparison of per capita relationships [16]

Comparison of Household Efficiency Rates

As would be expected, the replacement of the fixtures and appliances had a significant impact on the percentage of homes that passed the efficiency criteria described above. A comparison of these percentages is shown in Figure 48. Even with the high performance levels of the devices installed in these homes there was enough variation in performance that it took these high standards to assure that nearly all of the homes in the sample met the efficiency criteria that we have been striving to reach since the 1990's. The net result of the effort was that in the retrofit group nearl all of the homes had average flush volumes less than 2 gpf, clothes washer volumes of less than 30 gpl and shower flow rates less than 2.5 gpm.

16 Source Z:\Projects\ABCWUA\Task 2 Baseline Data Logging\task 2.4 analysis\percapita use relationship.xls

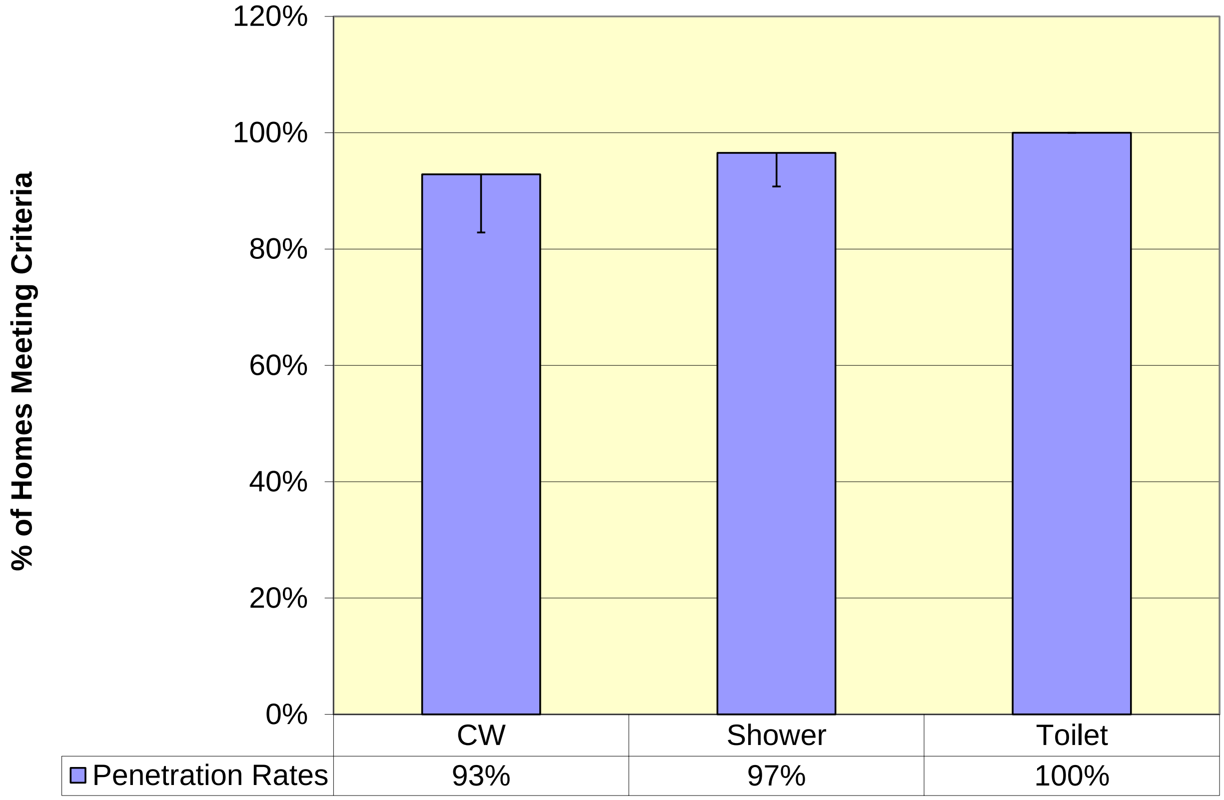


Figure 48: Comparison of household efficiency rates

Discussion of Water Savings

As a result of the retrofits the indoor water use in the study homes dropped to an average of 101 gphd. Assuming that this daily use pattern can be reproduced throughout the service area the total potential savings will depend on the household water use prior to the retrofit. This is demonstrated in Table 46. This table lists the pre and post water use by end use for the Logging Group, which represents the indoor water use of the service area population, and for the retrofit group, which is generally similar to the indoor use of the upper quartile of water users.

As shown in the table, the potential savings is much larger when compared to the pre-retrofit homes than when compared to the general population. Potential savings compared to the population of homes is estimated at 14.6 kgal per home per year, while against the retrofit group baseline use the savings are estimated at 23.2 kgal per home per year.

Table 46: Summary of Water Savings

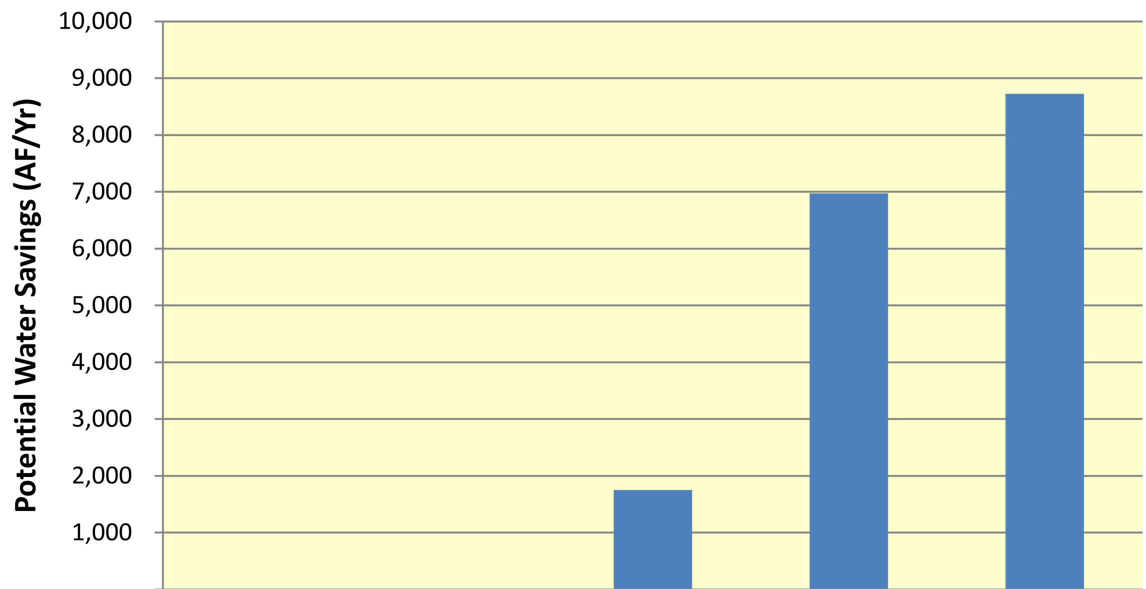
End Use	Logging Group (gpd)	Pre-Retrofit Group (gpd)	Post-Retrofit Group (gpd)	Savings over Logging Group (gpd)	Pre and Post-Retrofit Savings (gpd)	Average Savings Kgal/yr.	Top Quartile Savings Kgal/yr.
Toilets	31.8	47.1	19.6	12.2	27.5	4.5	10.0
Clothes washers	26.2	33.6	17.1	9.1	16.5	3.3	6.0
Showers	28.0	30.8	26.8	1.2	4.0	0.4	1.5
Faucets	22.6	30.8	24.6	0	6.2	0	2.3
Leaks	23.1	23.9	6.5	16.6	7.4	6.1	2.7
Bath	2.8	4.6	3.2	0	1.4	0	0.5
Dishwasher	1.5	1.9	1.9	0	0	0	0
Other	1.9	1.7	1.1	0.8	0.6	0.29	0.2
Total	**137.9**	**174.3**	**100.8**	**39.9**	**63.6**	**14.6**	**23.2**

This analysis can be taken a step further by analyzing the baseline use of the Logging Group after breaking its water use into quartiles. Table 47 shows the baseline water use for the Logging Group applied to the population of 143,194 active single family accounts based on 2009 billing data. The Logging Group was selected to match the indoor water use of the population, so it is a safe assumption that the quartile water use of the Logging Group will be similar to that of the population of active single family accounts.

As shown in Table 47 the estimated savings is not evenly distributed among the water use quartiles. The lower two quartiles are not expected to have any significant savings since their baseline water use was less than the target use after the retrofits. The water savings from the third quartile are projected to be 1750 AF/Yr, while the savings from the top quartile are projected at 6974 AF/Yr. The total estimated potential savings from the active single family accounts is projected to be 8724 AF/Yr. The skewed nature of the water savings is demonstrated graphically in Figure 49.

Table 47: Potential Water Savings by Quartile

Quartile	Weighted Average Baseline Use	Target Use	No. HH's	Potential Savings for Quartile		Percent of Total
	(gphd)	(gphd)	N	(gpd)	(AF/Yr)	%
1	49	101	35,799	0	0	0
2	97	101	35,799	0	0	0
3	145	101	35,799	1,562,349	1,750	20
4	275	101	35,799	6,225,624	6,974	80
Total			**143,194**	**7,787,973**	**8,724**	**100**



	1	2	3	4	Total
(af/Yr)	-	-	1,750	6,974	8,724

Figure 49: Projected water savings from interior retrofits by quartile

Factors that Affect Water Use in Albuquerque

The water use data from the 2009 billing records and flow trace analyses were used in combination with the survey results to explore the factors that affect water use in Albuquerque. The results in this section are meant to be more qualitative than quantitative. We rely more on the pre-post analysis described above to quantify the potential savings from the program.

Analysis of Water Waste Violations

The Water Authority provided a dataset that contains a record of all water waste violations for the period from January 1, 2000 to December 31, 2009. This contains a total of 6620 records. Each record provides an ID number, a case number, the date of the citation, the cumulative number of violations having been received by the customer, the amount of the fine, and the account number.

According to the ABCWUA Website, the following procedure is used for assessing water waste violations:

1. Most water waste cases begin with a complaint from the public.
2. Water waste is observed and documented by water waste enforcement staff.
3. A notice-of-violation is sent by certified mail to the water billing address within fifteen days of the water waste observation. The notice informs the customer that a fee for the water waste will be assessed on the next water bill.
4. A customer may contact the water waste enforcement person who signed the notice to ask questions or arrange to view the videotape.
5. A customer who has received a notice-of-violation may contest the fee assessment by filing a written request for a hearing with the Executive Director of the Water Authority.
6. The Executive Director must receive the request within seven days of the notice-of-violation (see "How do I contest the fee assessment?").
7. If the fee assessment is not contested or if the fee assessment is upheld by the Executive Director, the fee is included on the next water bill. Water waste fees must be paid like any other charges on the water bill.

Repeat violations are subject to higher fines, as shown in Table 48

Table 48: Fine amounts versus number of violations received

Number of Violation	Amount of Fine
1	$20
2	$50
3	$100
4	$300
5	$400
6	$600
7	$800
8	$1000
9	$2000

The analysis of the citations received in the billing data is provided in Table 49. The table shows the breakdown of the number of citations in the various amounts. Over half of the citations issued during the period were first time offenses, but these accounted for just 11% of the total income from the fines. There were a total of 147 citations issued at the $1000 or more level, which contributed 28% of the total revenue from the program. It also appears from the data that a large number of repeat violations went to the same individuals because the number of citations is greater than the number of accounts to which citations were sent. It was not possible to analyze the impact or citations on the logging group because too few members of the logging group had received citations.

Table 49: Summary of Water Waste Violations

Amount of Fine	Number of Citations	Total Amount	Percent of Total $	Percent of Violations
20	3583	$71,660.00	11%	54%
40	342	$13,680.00	2%	5%
60	1057	$52,850.00	8%	16%
100	695	$69,500.00	11%	10%
160	174	$26,100.00	4%	3%
200	191	$38,200.00	6%	3%
300	201	$60,300.00	10%	3%
400	116	$46,400.00	7%	2%
500	19	$9,500.00	2%	0%
600	65	$39,000.00	6%	1%
800	30	$24,000.00	4%	0%
1000	103	$103,000.00	16%	2%
1200	11	$13,200.00	2%	0%
1600	7	$11,200.00	2%	0%
2000	26	$52,000.00	8%	0%
	6620	$630,590.00	100%	100%

As shown in Table 50 the year with the maximum number of citations mailed was 2004, when 1026 were sent out. The average during the ten year period was 662. There does not appear to be a trend in the number of citations issued during this period.

Table 50: Number of citations by year

Year	Number of Citations Issued
2000	273
2001	397
2002	525
2003	633
2004	1026
2005	777
2006	606
2007	447
2008	975
2009	961
Total	6620
Average	662

As was the case with attempting to analyze the impact of rebates on water use, with just a single year of billing data it is not possible to determine whether or not receiving a citation for water waste led to changes in the water use of individual accounts. The data do show, however, that accounts that have received citations have significantly higher water use than both the general population and the survey respondents who were included in the logging study group. The annual use of accounts with violations is between 170% and 190% of the use of customer who have not received citations. The biggest difference in use is in the seasonal use category. The customer who received citations earlier in the period had slightly lower use than those who received citations later. This might indicate that the early violators took actions to reduce their use, but is not proof that the citations have led to reductions in water use.

Table 51: Comparison of water use between violators and non-violators

Violation Status	Number of Accounts with 2009 Data	Annual Use 2009	Seasonal Use 2009	Non-seasonal Use 2009
Non-violators	148,218	94.11	32.12	61.99
Survey Group	209	130.2	37.6	65.6
Violation received between 2000-2006	1477	161.02	78.13	82.89
Violation received after 2006	919	177.52	95.70	81.82

The most convincing way to demonstrate whether both the citations and rebates have had an affect on the water use of the customer to which they apply would be to do a time series analysis of the water use for these accounts a few years befor and after receiving a rebate or a citation. If there have been water use change due to either of the factors then the change will be seen in the billing data.

Indoor Use Versus Number of Residents

Data from the logged sample were used along with the survey reponses to examine which factors best explain the indoor water use for the logged sample. The first step was to develop a model using the continuous variables in which the dependent variable was the indoor gallons per day and the dependent variables were: number of residents, income, number of bathrooms, number of bedrooms, age of home. This analysis showed that the only continuous variable that was significant in predicting indoor water use was the number of residents living in the home. The rest of the variables were not predictive for indoor use. The model that resulted from this analysis was as shown in **Table 45**. Various conditional variables were also examined as to their impact on indoor water use.

Impact of Retrofits

The impact of retrofits was tested by comparing the average percentage of toilets in the homes that were reported in the survey as ULF, HET or Dual Flush, and the number of shower heads that were reported at low flow versus whether or not the household had received a rebate. The results of this analysis are shown in Table 52 . This table shows that homes that have had any rebate tend to have higher percentages of ULFT toilets and low flow shower heads than homes that have had no rebates. There was no difference in the percentages reported for either HET's or dual flush toilets.

Table 52: Impact of Rebates on Penetration of high efficiency devices

Rebate status (1995-2009)		Percent ULFT	Percent HET	Percent Dual Flush	Percent Low Flow Showers
Any rebate	Mean	48%	6%	4%	39%
	N	174	174	174	173
No rebates	Mean	34%	7%	4%	28%
	N	96	96	96	96

Showers

There was a very weak correlation between daily shower use and a number of factors derived from the survey. Homes with combination shower/tubs tended to use slightly more water than homes with shower stalls. Homes in which the survey indicated the presence of low flow shower heads tended to use less water than average and homes. There were a total of 14 homes with multi-headed showers, and these had slightly greater shower use. As shown in Table 53 , while none of the factors reached statistical significance, the slopes of the lines were at least in the direction that makes intuitive sense.

Table 53: Correlation factors for shower use

Factor	Pearsons Factor (r)	Significance (p)
Bath/shower combinations	.073	.269
Stall Only showers	-.039	0.586

Survey shows low flow heads	-.062	.379
Multi-heads installed	.111	.087

Toilets

The data showed that homes with ULF or better toilets, based on the flow trace analysis, used an average of 10 gphd less water than homes with standard toilets. There were a total of 86 homes in the baseline group that had toilets that met this criterium based on the analysis of the flow traces. Interestingly, a total of 103 homes responded to the survey that they believed they had ULF toilets. These homes showed no difference in indoor water use. In this analysis, and the remaining analyses in this section, the impacts of the factors have been adjusted for the number of persons in the home using ANOVA process.

Paying for Water

Only a single household out of the logging sample did not pay for their water themselves. Consequently, it was not possible to examine the impact of paying for water on water use.

Front Loading Clothes Washers

Based on the survey, there were 73 homes with front loading clothes washers during the baseline logging. The impact of having a front loading machine was a reduction in the indoor use of approximately 15 gphd.

Presence of Youth in Home

In the study of single family homes in California a negative correlation between the presence of a non-adult in the home and indoor water use was observed. This was not the case in the Albuquerque study. The difference in indoor use was negligible between homes with young people living there, and without.

Presence of a Stay-At-home During the Day

The data do show that there was a positive correlation between having someone at home during the day and indoor water use. In this case homes with someone at home during the day used an average ofr 13 gphd more water.

Swimming Pools and Spas

Fifteen of the homes in the logging group had swimming pools. These homes also had average indoor water use of 18 gphd more than the homes without pools. This is probably because the homes with pools had more water use for the pool that gave the appearance of indoor faucet use during the analysis.

Homes with outdoor spas or hot tubs had an even larger difference in indoor use. In these cases the average indoor was as over 50 gphd greater. There were only 18 of these homes, but the difference in use is so large that the results are worth taking note of. As with the pools, it is believed that the spas and hot tub use appears on the flow traces as faucet use, which is classified as an indoor use, even though the device using the water may be located outside the home.

Garbage Disposals

There were 42 homes that did not have garbage disposals and 166 that did. The average indoor water use in the homes that had disposals was 24 gpdh lower than the homes without these appliances. A similar finding occurred in the California study. We believe that the direction of the change (i.e. that there is a negative correlation between disposals and indoor water use) is more significant than the size of the reduction will always be 24 gphd.

Dish Washsers

Homes with dish washers also tended to use less water than homes without. There were a total of 38 homes that did not have dish washers. The impact of having a washer was a reduction in indoor water use of approximately 7 gphd.

Swamp Coolers

There were 150 homes with swamp coolers and 58 without. The ANOVA analysis showed that the homes with swamp coolers tended to use 6.5 gphd more water during the logging period.

Attitudinal Responses (Q28)

None of the attitudinal responses to Question 28 in the survey were linked with a change in observed water use during the logging period, but they did show that the customers had strong opinions on water issues. The fact that there was such unanimity on the issues reduced the potential of seeing impacts because there was not a large enough group of dissenters to compare against.

Summary and Conclusions

In summary, this study has shown that the use of current best available technology in interior upgrades to fixtures and appliances is capable of reducing indoor water use for a family of 3 to 95 gphd, or approximately 32 gpcd. The retrofits that were shown to have the greatest value in this effort were toilets, clothes washers, faucets, and showers. Savings were not evenly distributed among all groups of customers, and over 80% of the projected savings were attributed to the top quartile of users. The following summarizes the equipment used for the study.

- For toilets, the criteria is the use of HET type toilets, which had a design average flush volume of 1.28 gpf
- For clothes washer the criteria is the use of CEE Tier 3 or better machines.
- Showers were selected that use 1.7 gpm
- While no specific leak detection and control devices were used for the study it appears that the replacements had the ancillary benefit of reducing leaks.
- A combination of high efficiency faucets, including one touch kitchen faucets and manual faucet aerators that had quick shut off devices.

The average indoor water use dropped to 101 gphd as a result of the retrofits in the study homes, when normalized for a family of three the projected indoor use was 94 gphd, or 31 gpcd. This compares to a baseline use of 138 gphd in the population and 174 gphd in the retrofit group baseline use.

The total water savings from extending the program to the Authority service area was projected at 8724 AF per year. This represents a significant amount of water, or nearly 20% of the total single family water use in 2009.

The toilets, clothes washers and showerheads all resulted in significant reductions in water use. The showers were somewhat obscured by the higher showering rate in the retrofit homes, but on a per shower basis they resulted in a 25% reduction in water use. The faucet interventions were not as clear. The faucet use remained similar before and after the retrofits. The program impacted leakage, probably due to repairs of large leaks in a few homes.

The study was not a cost effectiveness analysis, and it is left to future planners to determine what types of conservation programs would be cost effective in order to capture the potential saving demonstrated in this study. There are a number of ways that the required indoor retrofits can be accomplished without major commitments of money by the Water Authority.

There was a high degree of satisfaction with the retrofit devices. The average rating for the toilets was 4.8 out of a possible 5. The ranking for the clothes washers and shower heads was 4.6 out of 5. The Delta One-touch kitchen faucets were also well received, obtaining a rating of 4.8 out of 5. Most of the participants would recommend the devices to friends. Details of the ratings are provided in Appendix C.

The study indicated that for Albuquerque there are greater savings from indoor programs than outdoor; at least compared to outdoor programs based on elimination of excess irrigation. This is not necessarily an expected result. Still, the data do seem to point in this direction.

The fact that the projected water savings are derived from indoor use, which is largely non-consumptive does not diminish their value give the fact that Albuquerque used a combination of groundwater and imported water from mountain storage in the San Juan River basin. Reduction in withdrawals from groundwater are of great importance in extending the life of local aquifer. Reductions in releases from headwater reservoirs will allow for additional carry-over storage and an increase in system reliability and drought resilience. In a system that is supply limited reductions in all diversions is a benefit.

The key to design of a cost effective conservation plan is to determine the marginal value of the water that will be saved by the conservation program and the time frame over which the savings are needed. The higher the marginal value of the water the greater the expense that can be justified in conservation. Also, the longer the time frame over which the savings can be allowed to mature the less cost will be the program. Programs that rely on codes, natural replacements and upgrades on sale can achieve wide upgrades in performance at little direct cost. In Albuquerque's case if we are considering savings of 8700 AF at a marginal cost of $10,000 per acre foot the total capital value of the saved water would be $87 million. This would have an annual value of approximately $8 million per year. These values, while very preliminary, give an idea of the value of the resource which is at stake, and help define the range of annual expenditures that could be justified.

Based on these responses to question 28 of the survey there is a strong probability that the Albuquerque water customers would support taking a more active role in managing water, and would support financial incentives for conservation and avoiding waste.

The City of Albuquerque is faced with water planning challenges over the coming years. This study has shown that there is a potential to generate nearly 9000 acre feet of supply through conservation, and this water is certainly going to be less expensive and environmentally damaging than traditional demand side efforts. While conservation is not a panacea it is very important to recognize its potential, and factor in its impacts on water supply and operations studies in the future. We hope that the results of this study will assist the water planning efforts of the City and Water Authority and lead to better integrated planning.

Appendix A – Survey Instrument and Results

Results from the 476 returned surveys are shown in purple text. In some cases, responses may not total 476 due to incomplete or unclear answers to specific questions.

Results from 476 Returned Household Water Use Surveys

Indoor Water Fixtures and Appliances

1. **Please indicate how many of each of the following types of water-using appliances or fixtures you have in your home. Please circle the appropriate number for each.**

	None	One	Two	Three	Four	Five	Six	Seven or more
Toilets	0	39	302	114	14	5	1	0
Bathtub with shower	12	312	129	6	0	0	0	0
Standard Bathtub only	217	77	8	0	0	0	0	0
Whirlpool tub w/jets	242	73	3	0	0	0	0	0
Shower stall only	90	286	32	4	0	0	0	0
Indoor utility/garage sink	247	76	6	0	0	0	0	0

2. **Please indicate whether you have any of the following inside your home. Please check the appropriate box for each.**

	Yes	No
Garbage disposal	378	98
Top-loading clothes washing machine	296	180
Front-loading clothes washing machine	174	302
Dishwashing machine	392	84
Indoor spa or hot tub with jets (if hot tub is NOT usually filled with water, indicate "no")	26	450
Evaporative/swamp cooler	346	130
A built-in indoor water feature (like a water fountain or water pond)	10	466
A "whole house" water treatment system like a water softener or a reverse osmosis system	49	427
Pets	305	171
Indoor garden or greenhouse	17	459

3. **How many of the toilets in your home are ULF, HET, or Dual flush models?**

	None	One	Two	Three	Four or more	Don't Know
ULF (1.6 gallons)	80	61	124	39	6	39
HET (1.28 gallons or less)	143	20	13	8	1	143
Dual Flush (~1.6/0.8 gallons)	168	7	11	2	0	168

(The flush volume of ULF and HET toilets are normally marked behind the seat in front of the tank)

4. **How many of the showers in your home have low-flow (water conserving*) showerheads?**

	None	One	Two	Three	Four or more	Don't Know
showerheads?	188	99	99	15	1	99

**2.5 gallons per minute (gpm) or less, usually stamped on the showerhead*

5. **Do any of the showers in your home have multiple showerheads?**

50 Yes → **How many showers have multiple heads?** 42 **have one** 8 **have two (max reported)**

426 No

Household Water Use Survey Page 2 of 8

6. Please indicate whether you have replaced any of the following since 1995. Please check the appropriate box for each.

	Yes	No
Toilets	244	232
Showerheads	318	158
Clothes washer	315	161

7. Please indicate whether you have any of the following. (Please check all that apply.)

	Yes	No
Leaking toilet (you can hear it running when not in use)	48	428
Dripping faucet	69	407
Leaks in your swimming pool system	7	469
Leaks in your irrigation system	39	437
Other water leaks	33	443

8. What type of water heater do you have in your home? (Please check all that apply.)

Gas	445
Electric	15
Propane	0
Solar	1
Other	1
Don't know	6

9. Do you have a remedy to try and eliminate or reduce "waiting for hot water"?

101 Yes → **go to question 10**
375 No → **go to question 11**
0 Don't Know → **go to question 11**

10. What remedies have been installed? (Please check all that apply.)

13 Tankless water heater
5 On-demand system (recirculating pump that goes on when I push a button)
28 Catching water in a bucket for reuse
11 Other ____________________
41 Recirculating pump installed on hot water system →

How does the recirc. Pump work?
12 It runs all the time
25 It is controlled by a timer clock
5 Don't know
2 Other ____________

Outdoor Landscape

11. Do you regularly water your outside landscape?
(Includes hand watering, irrigation system, hose and sprinkler, or other method.)

424 Yes   52 No → **go to question #22**

12. Do you use a landscape service for any part of your outdoor mowing and/or maintenance?

42 Yes   383 No → **go to question #14**

Household Water Use Survey **Page 3 of 8**

13. Is your landscape service provider responsible for adjusting your outdoor landscape watering schedule?

7 Yes 35 No

14. In addition to the water purchased from your water utility, do you use any of the following sources of water for your outdoor water needs? (Please check all that apply.)

No additional sources of water used	331 Yes	114 No
Well water	10 Yes	414 No
Canal/ditch	5 Yes	419 No
Stream/river	1 Yes	423 No
Rain barrel or cistern (rainwater harvesting)	59 Yes	365 No
Directing roof/rain water towards plants in the yard	30 Yes	394 No
Gray water reuse from indoor fixtures	13 Yes	412 No
Other: ______________________________		

15. Which types of landscape are present in your yard? (Please check all that apply.)

Turf (any variety)	237 Yes	190 No
Non-native deciduous trees and shrubs	244 Yes	187 No
Vegetable garden	148 Yes	279 No
Desert/native trees and shrubs, cacti, or other xeric plants	278 Yes	160 No
Non-living ground cover (mulch, gravel, rocks, etc.)	314 Yes	124 No

16. About how much of your outdoor landscape is watered by hand/manually?

120 All of it (100%)
45 More than half
187 Less than half
76 None

17. Do you have an in-ground irrigation system?

254 Yes 173 No → **go to question 22**

18. Does your in-ground irrigation system have an automatic timer?

216 Yes 38 No

19. How frequently do you adjust the run times on your irrigation timer

13 I use the factory settings that came with the timer
81 Once a year, at the start of the irrigation season
96 Once a month
11 Once a week
28 Don't know

20. Does your automatic irrigation system have an override shut-off device such as a soil moisture sensor or rain sensor? (Please check all that apply.)

195 No override shut-off device
5 Yes, soil moisture sensor installed
9 Yes, rain sensor installed
3 Other ______________________________
28 Don't know

Household Water Use Survey *Page 4 of 8*

21. **Does your automatic irrigation system have a weather-based irrigation controller (WBIC) or "smart" controller?**
416 No 8 Yes 52 Don't know / Blank

Outdoor Water Fixtures

22. **Does your home have an <u>outdoor</u> spa or hot tub?**
39 Yes 437 No → **go to question #24**

23. **Is the outdoor spa or hot tub usually filled?**
26 Yes, usually filled
10 No, sometimes filled
3 No, it is never filled

24. **Do you have an outdoor water feature like a fountain or pond that is filled regularly?**
70 Yes 406 No

Swimming Pools

25. **Does your home have a swimming pool?**
37 Yes
439 No → **go to question #28**

26. **What type of filling/re-filling system does the swimming pool have?**
33 Manual 2 Automatic

27. **Do you have a swimming pool cover that you use when the pool is not in use?**
34 Yes 442 No

Finally, we would like to know just a little more about your household so we can learn how attitudes might affect water use.

28. **Please indicate the extent to which you AGREE or DISAGREE with each of the following statements. Please check the appropriate box for each.**

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	Not Applicable
A. Residents should be able to track their household water use by reading their own water meter.	187	207	49	19	14
B. Households would conserve more water if they had an easier way to monitor their water use.	209	204	48	12	3
C. The cost of water is an important factor for me when deciding how much water to use.	165	192	81	32	6
D. Most households in Albuquerque know where their water comes from when they turn on the tap.	39	98	178	156	5
E. Conservation of water is critical for the future of Albuquerque.	408	57	2	9	0
F. There should be strong financial penalties for people who use too much water	149	212	83	28	4
G. I am aware of rebates offered by the Water Authority.	119	171	70	102	14
H. I follow the Water By The Numbers program when setting my irrigation schedule.	184	131	44	20	97

Household Water Use Survey Page 5 of 8

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	Not Applicable
I. Water rates should be increased to encourage water conservation.	37	111	151	174	3
J. I conserve water to save money.	156	210	62	43	5
K. I conserve water to save energy.	170	213	57	28	8
L. I conserve water because it is the right thing to do.	294	165	6	8	3

29. Is your household responsible for paying the water bill, OR does a landlord or homeowners' association pay it?

465 Household pays
6 Landlord or a homeowner's association → **go to question #32**
Don't know → **go to question #32**

30. When was your home built?

0 Before 1940
54 In the 1940s
85 In the 1950s
47 In the 1960s
85 In the 1970s
0 In the 1980s
81 Between 1990 and 1994
68 Between 1995 and 2000
30 Between 2001 and 2005
10 Between 2006 and 2010

31. In what year did you move to this home? Average year is 1991 Median year is 2000

32. How many bedrooms does this house have?

❑ one bedroom: 5
❑ two bedrooms: 66
❑ three bedrooms: 266
❑ four bedrooms: 120
❑ five bedrooms: 12
❑ six or more bedrooms: 4

33. How many people, including yourself, live full-time at this address?

Adults, including yourself (age 18+) Average: 1.97 Median: 2

Teenagers (age 13-17) Average: 0.60 Median: 0

Children (age 3-12) Average: 0.90 Median: 1

Infants or Toddlers (under age 3) Average: 0.40 Median: 0

34. What number of adults living at this address are NOT employed (or students) outside of the home?

220 None
152 One
83 Two
10 Three
3 Four
0 Five or more

35. How many times per week does someone take a bath in your household?

170 None
38 One
26 Two
29 Three
41 Four
161 Five or more

36. How many times per week does someone in your home take a shower at an athletic club or recreation center instead of at home?

379 None
14 One
25 Two
24 Three
11 Four
16 Five or more

37. Do you rent or own your residence?

Household Water Use Survey *Page 6 of 8*

25 Rent 446 Own

38. About how much do you estimate your household's total income before taxes was last year? (Please check the appropriate box below.)

	Income range	Number of respondents	Percent of respondents
Less than	$10,000	14	3.1%
$10,000 to	$19,999	28	6.3%
$20,000 to	$29,999	35	7.9%
$30,000 to	$39,999	58	13%
$40,000 to	$49,999	46	10%
$50,000 to	$59,999	44	9.9%
$60,000 to	$69,999	35	7.9%
$70,000 to	$79,999	34	7.6%
$80,000 to	$89,999	37	8.3%
$90,000 to	$99,999	23	5.2%
$100,000 to	$109,999	22	4.9%
$110,000 to	$119,999	69	15.5%
$120,000	or more	0	0.0%

39. Please provide any other information you believe would be useful for the study.

Thank your for taking the time to assist with this important research project. All of your answers will be kept confidential.

Please fold and send using U.S. mail in the pre addressed and stamped envelope.

Aquacraft, Inc.
2709 Pine Street, Boulder, CO 80302
303-786-9691; www.aquacraft.com

Appendix B – Verification Letter

July 2010

Dear Valued Water Customer:

Congratulations! You have been selected to participate in the next phase of the Water Authority's Water Use Efficiency and Retrofit Study.

All the customers who agreed to participate by filling in and mailing back the Household Water Use Survey were added to a list of candidates and your home is one of 240 homes selected to proceed to the next phase of this study. That means your home now has a greater chance of receiving, at no charge, new water-efficient fixtures and appliances valued at up to $3,400. These water saving products include the industry's best performing high-efficiency toilets, faucets, showerheads, and clothes washers.

This study will allow us to obtain data on how effective such water-saving devices are at reducing water use, which is vital information for our system planning.

In the coming weeks and months a technician from the project's consulting firm, Aquacraft, Inc., will install a data logger on your curbside water meter. This logger will be left on the meter for two weeks and will provide us with detailed information about water use patterns of your home. All that is asked of you is that your home continues to use water as normal. That is all there is to it. No one will enter your home or disturb you.

After the data from these 240 homes are analyzed, ***a group of 30 or more homes will be selected for the retrofit portion of the study, and will receive the new fixtures and appliances mentioned above.*** The water-saving equipment, worth up to $3,400, will be installed during the fall of 2010, and these homes will be re-logged so we can measure the water savings.

If you have any questions, please contact Frank Roth at 505-768-2511 or froth@abcwua.org. Thank you for aiding the Water Authority in planning for our community's water future.

Sincerely,

Mark S. Sanchez
Executive Director

Appendix C – Retrofit Devices by Household

Table 54: Installed and retrofit devices

Keycode	Kitchen Aerator	Kitchen Delta H2O Touch	Top load HE Clothes Washer	Front load HE Clothes Washer	# of HET	Type of Toilet (DF, SF)	Toilet Model (Kohler)	Aerator				Showerhead (Kohler)	
								Stnd	On/off	Push n Flow	Smart	Handheld	Stnd
10S404	0	1	1	0	3	DF	Sterling Karsten 402028-0		0	5		2	0
10S407	0	1	0	0	2	SF	Highline K-3889-0	2*	0	1		1	1
10S409	0	1	0	1	2	DF	Sterling Karsten 402025-0		0	2		1	1
10S414	0	1	0	1	2	SF	Highline K-3889-0		0	2		2	0
10S416	0	1	0	1	2	SF	Highline K-3889-0		0	2		0	2
10S417	0	0	0	1	3	DF	Sterling Karsten 402028-47		0	0		0	3
10S421	0	0	1	0	2	SF	Wellworth K-3997-0		0	2		2	0
10S424	0	1	0	0	2	DF	Sterling Karsten 402028-0	3*	0	0		0	2
10S425	0	1	1	0	1	DF	Sterling Karsten 402025-0		0	1		0	1
10S429	1	0	1	0	2	SF	Wellworth K-3997-0		0	2		2	0
10S430	0	1	1	0	2	SF	Wellworth K-3998-0		4	0		2	0
10S435	0	1	0	0	3	DF	Sterling Karsten 402025-0		0	5		2	0
10S439	0	1	1	0	2	SF	Wellworth K-3997-0		2	0		0	2
10S440	0	1	1	0	2	SF	Wellworth K-3997-0		2	0		2	0
10S442	0	1	1	0	3	DF	Sterling Karsten 402028-0	1*	3	0		0	2
10S444	0	1	0	1	2	SF	Wellworth K-3998-96		0	2		2	0

Keycode	Kitchen Aerator	Kitchen Delta H2O Touch	Top load HE Clothes Washer	Front load HE Clothes Washer	# of HET	Type of Toilet (DF, SF)	Toilet Model (Kohler)	Aerator				Showerhead (Kohler)	
								Stnd	On/off	Push n Flow	Smart	Handheld	Stnd
							Wellworth K-3997-96						
10S448	1	0	0	0	3	SF	Sterling Karsten 402025-0		3	0		0	2
10S450	0	0	0	0	3	DF	Sterling Karsten 402025-47		0	5		0	3
10S461	0	1	0	1	2	SF	Wellworth K-3997-47		0	2		0	2
10S465	1	0	1	0	2	SF	Highline K-3999-0 Wellworth K-3948-0		0	3		1	1
10S469	0	1	0	1	2	SF	Wellworth K-3998-0 Wellworth K-3997-0		0	0		0	2
10S475	1	0	0	0	3	DF	Highline K-3889-0 Sterling Karsten 402028-0		0	2		1	2
10S477	0	1	0	1	3	SF	Wellworth K-3997-0		0	4		0	2
10S479	0	1	0	0	3	DF	Sterling Karsten 402028-0		0	2	1	0	3
10S492	1	1	0	0	2	SF	Highline K-3889-0	1*	0	1		1	1
10S497	0	1	0	1	2	SF	Wellworth K-3997-0	1*	0	2		0	2
10S502	0	1	1	0	2	SF	Highline K-3889-0	2	0	0		2	0
10S504	0	1	1	0	2	DF	Sterling Karsten 402025-0 Sterling Karsten 402028-0		1	1		0	2
10S509	1	0	1	0	2	DF	Sterling Karsten 402028-0 Sterling Karsten 402025-0		0	2		0	2
Total	**6**	**21**	**12**	**9**	**66**			**10**	**15**	**48**	**1**	**23**	**37**

Table 55: High efficiency clothes washer performance survey

Keycode	Cleaning of clothes	Maintenance /Reliability	Noise	Moisture content of clothes	Cycle selection	Capacity	Wash cycle time	Detergent use	Experienced problems with HEW?	Comments
10S404	4	5	4	5	3	5	4	4	1	Spin cycle creating wrinkles - inability to slow it in cotton cycles
10S409	5	5	5	4	4	4	5	4	0	
10S414	5	5	5	5	5	4	5	5	0	
10S416	5	5	5	5	5	5	5	5	0	
10S417	5	5	5	5	5	5	5	5	0	
10S421	5	5	5	5	5	5	4	5	1	Didn't read how to properly load clothes and the 1st load I did was tied in knots! I read instructions and now am delighted!
10S425	5	5	5	5	5	5	5	5	0	
10S429	5	5	5	5	5	5	5	5	0	
10S430	2	3	3	3	2	4	4	4	1	It has destroyed a lot of clothes and all 3 of the throw rugs that I've washed in it. I never had a problem washing them in the other washer, and after one wash in this one they're frayed and have holes all over! Clothes come out destroyed, pulled out of shape, and mashed into little crumpled balls. It often leaves detergent bits on the clothes.
10S439	4	5	5	4	5	5	4	5	0	
10S440	5	5	4	5	5	5	5	5	0	
10S442	5	5	5	5	5	5	4	5	0	
10S444	5	5	5	5	5	5	5	5	0	

10S461	2	5	3	5	5	2	3	5	-1	It vibrates a lot and the clothes are not balanced in it. Mainly when washing sheets and towels, but it vibrates at other times.
10S465	3	3	3	4	4	4	4	4	1	Occasionally the clothes are not dry.
10S469	5	5	5	5	5	5	5	5	-1	
10S475										
10S477	5	5	3	5	5	5	4	5	0	
10S497	5	5	5	5	5	5	4	5	1	The highest spin cycle is a little fast. Fixed the problem by using the medium spin cycle.
10S502	4	4	4	4	4	5	4	5	0	
10S504	5	5	5	5	5	5	5	5	0	
10S509	5	5	5	5	5	5	5	5	0	
Average	**4.5**	**4.8**	**4.5**	**4.7**	**4.6**	**4.7**	**4.5**	**4.8**		

Code	
1	Dissatisfied
2	Somewhat dissatisfied
3	Neutral
4	Somewhat satisfied
5	Completely satisfied

Table 56: High efficiency clothes washer satisfaction survey

Keycode	Does HEW have extra rinse option?	How often use extra rinse option? (1 = always, 2 = sometimes, 3= never, 4= not sure)	Compared to old HEW do you like new HEW? (1 = more, 2 = same, 3= less, 4= not sure)	Recommend HEW to others? (1=yes, 0=no, -1=not sure)	If buying own pay $150 more for HEW? (1=yes, 0=no, -1=not sure)	What would you have manufacturer change about HEW?	Comments on HEW
10S404	1	3	1	1	1	Spin speed adjustment	
10S409	1	2	1	1	0		
10S414	1	3	1	1	-1		
10S416	1	2	1	1	1		
10S417	1	3	1	1	1		
10S421	1	3	1	1	1	Default to cold/tap water selection	
10S425	1	3	1	1	0	Not to make the washer top so sloped	Love how you can program it to come on at 5 am. Love how it senses everything how there's a dispensing compartment. I love it completely. Totally.
10S429	1	3	1	1	1		
10S430	1	2	3	-1	-1	Make it gentler on my clothes! It doesn’t matter if our clothes are clean when they're DESTROYED! We'll need new wardrobes and rugs before the year is up!	Hate it! It beat the heck out of the clothes! If someone wants to trade their front-loader for this, I'll trade in an instant! Hate it! (I mean, thanks for the freebie, but we'll spend more than the cost of the washer on new clothes and rugs!
10S439	1	3	1	1	1	Allow the lid to	

						open during washing	
10S440	1	3	1	1	1		
10S442	-1	3	1	1	-1		
10S444	1	2	1	1	1	Could sit up higher but we weren't given that option.	
10S461	1	3	3	0	1	The capacity is not adequate for my large family. It will only wash 5-6 towels.	The clothes sometimes smell. I have to use fabric softener every load.
10S465	1	2	3	-1	0	To convince me that the clothes were clean - because so little water is used in the wash. My clothes aren't obviously dirty so - I can't be sure how clean they are.	Also: white socks in the "white" wash cycle have not been completely clean - looked grey on bottom of sock.
10S469			1	1	1	Nothing	
10S477	1	2	1	1	1		
10S497	1	3	3	0	1		
10S502	1	3	1	1	1	When the spin cycle is off balance - there is no instructions on how to correct the problem except to turn off the machine and	

						adjust the clothes. Perhaps an indicator light or beep?	
10S504	1	3	1	1	-1	None	None
10S509	1	2	1	1	1	Nothing	We are blessed to have it!

Table 57: High efficiency toilets satisfaction survey

Keycode	Compared to old toilets do your new toilets… (1 =more, 2=Same, 3=less, 4=not sure)			Recommend new toilet to others? (1=yes, 0=no -1=not sure)	How often use half flush if have DF? (1=always, 2=more than half, 3=half the time, 4=less than half, 5=never, 6= don't have DF)	One thing for manufacturer to change?	Comments on new toilet
	Clog	Require double flush	Require bowl cleaning				
10S404	3	3	3	1	2	Flush button - function to side, maybe a lever.	Like a lot - seat upgrade option would be nice stock seat is pretty flimsy
10S407	3	3	2	1	6		
10S409	3	1	2	1	3		
10S414	2	2	3	1	6	Can't think of any.	
10S416	3	3	3	1	6		
10S417	3	3	3	1	2		Working fine so far
10S421	3	3	3	1	6	Flatter tank cover	
10S424	4	3	1	1	2	Determine a way to clean the bowl better	
10S425	4	1	1	1	1	Less splash, easier way to clean toilet inside after the #2 since toilet is low flow	Smartly made so far. Very quiet.
10S429	3	3	3	1	6		
10S430	2	3	3	1	6	Make the sides (outside) smooth so that cleaning is easier.	They are fine
10S435	3	3	2	1	3	Move button to the side instead of center – can't put anything on the back of the toilet	
10S439	3	3	4	1	6		
10S440	3	3	3	1	6		
10S442	3	1	2		2		
10S444	2	3	1	1	6		Toilet in main bathroom is lower than the old one, and I don't like it as well

							because of that.
10S448	4	3	3	1	6		Love them.
10S450	4	3	1	1	1	Larger seat	
10S461	3	3	3	1	6	Flush handle should be towards the front. I have a cabinet around toilet and it is a little difficult to reach to the back to flush handle.	They are great and Silverado Plumbing did a very professional installation job.
10S465	3	3	2	1	6		
10S469	3	3	3	1	6	Perhaps a ceramic seat cover	
10S475	3	3	2	1	2		New toilets work great!
10S477	2	2	2	1	6		
10S479	3	3	2	1	1		
10S492	4	4	3	1	6		They're wonderful.
10S497	3	2	2	1	6		
10S502	3	3	3	1	6	Dual flush on all toilets	
10S504	2	1	2	1	2	Quieter flush	
10S509	3	3	1	1	1	Nothing, I don't mind using a brush bowl cleaner if I need to.	We are very blessed to have them!

Table 58: High efficiency toilet performance survey

Keycode	Bowl Cleaning	Flush Performance	Appearance	Noise	Leakage	Maintenance	Any flush performance problems	Explain
10S404	5	5	4	4	5	5	0	
10S407	5	5	5	4	5	5	0	
10S409	4	4	5	5	5	5	0	
10S414	5	5	5	5	5	5	0	
10S416	5	5	5	5	5	5	0	
10S417	5	5	5	5	5	5	0	
10S421	5	5	5	5	5	5	0	
10S424	2	5	5	5	5	5	0	Fecal matter is not always fully removed by flushing
10S425	3	5	5	5	5	5	0	
10S429	5	5	5	5	5	5	0	
10S430	5	4	4	4	5	5	0	
10S435	5	5	5	4	5	5	0	
10S439	5	5	5	5	5	5	0	
10S440	5	5	5	5	5	5	0	
10S442	4	5	5	5	5	4	0	
10S444	4	5	4	5	5	5	1	One clog, plunger got it cleared
10S448	5	5	5	5	5	5	0	
10S450	3	5	5	4	5	5	0	
10S461	5	5	5	5	5	5	0	
10S465	5	5	5	5	5	5	0	
10S469	5	5	5	5	5	5	0	
10S475	5	5	5	4	5	5	0	
10S477	5	5	5	5	5	5	0	
10S479	5	5	5	5	5	5	0	
10S492	5	5	5	5	5	5	0	
10S497	5	5	5	5	5	5	0	
10S502	4	4	5	4	5	4	0	
10S504	5	5	5	3	5	5	0	
10S509	5	5	5	5	5	5	0	
Average	**4.6**	**4.9**	**4.9**	**4.7**	**5.0**	**4.9**	**0**	

Code	
1	Dissatisfied
2	Somewhat dissatisfied
3	Neutral
4	Somewhat satisfied
5	Completely satisfied

Table 59: Performance survey of showerhead

Keycode	Handheld showerhead	Standard Showerhead	Water flow	Flow pattern	Appearance	Clogging	Adjustability
10S404	2	0	5	5	5	5	5
10S407	1	1	4	5	5	4	4
10S409	1	1	4	4	5	5	5
10S414	2	0	3	5	5	5	2
10S416	0	2	5	5	5	5	5
10S417	0	3	5	5	5	5	5
10S421	2	0	5	5	5	5	5
10S424	0	2	5	5	5	5	5
10S425	0	1	5	5	5	5	5
10S429	2	0	5	5	5	5	5
10S430	2	0	3	3	5	3	4
10S435	2	0	4	4	5	5	4
10S439	0	2	5	5	4	5	5
10S440	2	0	2	2	2	3	2
10S442	0	2	5	5	5	5	5
10S444	2	0	5	5	4	5	2
10S448	0	2	4	4	4	4	4
10S450	0	3	5	5	5	5	5
10S461	0	2	5	5	5	5	5
10S465	1	1	3	4	3	5	3
10S469	0	2	5	5	5	5	5
10S475	1	2	4	5	5	5	5
10S477	0	2	5	5	5	5	5
10S479	0	2	5	5	5	5	5
10S492	1	1	3	5	5	5	2
10S497	0	2	5	5	5	5	5
10S502	2	0	4	5	5	5	4
10S504	0	2	5	5	5	5	5
10S509	0	2	5	5	5	5	5
Count/Ave	**23**	**37**	**4.4**	**4.7**	**4.7**	**4.8**	**4.3**

Table 60: Satisfaction survey of showerhead

Keycode	Recommend showerhead to others? (1=yes, 0=no, -1=not sure)	Compared to old showerhead how like new? (1=more, same=2, 3=less, 4=not sure)	Compared to old shower time (1= shorter, 2=about the same, 3=longer, 4= not sure)	Comments about showerhead
10S404	1	1	2	
10S407	1	1	4	
10S409	1	1	1	
10S414	-1	1	2	Clamp holder for handheld showerhead is too weak and broke when trying to adjust. Showerhead clamp needs to be stronger.
10S416	1	1	2	
10S417	1	1	1	
10S421	1	1	2	
10S424	1	1	2	
10S425	1	1	2	I barely need to turn faucet on. The pressure is really wonderful. Feels softer on skin when it hits you.
10S429	1	1	2	
10S430	1	2	2	
10S435	1	2	2	
10S439	1	2	2	
10S440	-1	3	3	One showerhead drips constantly - will notify Aquacraft. The water flow is less so I do like that, pressure is lighter.

10S442	1	1	4	
10S444	1	2	4	Would have preferred shut offs for the showerheads, while soaping body or hair.
10S448	1	3	2	
10S450	1	1	2	
10S461	1	3	1	It really doesn't have high pressure for rinsing shampoo out of hair. So you have to stand there longer to get it all out.
10S465	0	3	2	
10S469	1	1	2	
10S475	1	1	2	
10S477	1	1	2	
10S479	1	1	2	
10S492	-1	3	3	
10S497	1	1	2	
10S502	1	1	1	
10S504	1	2	2	
10S509	1	1	1	We are blessed to have them! I can turn them off while I soap down or shampoo or shave my legs and when I turn it back on it's the same temp.

Table 61: performance survey for the Delta H_2O faucet

Keycode	Water flow	Flow pattern	Appearance	Clogging	Convenience	Ease of Use
10S404	5	5	5	5	5	5
10S407	5	5	5	5	5	5
10S409	5	5	5	5	5	5
10S414	5	5	5	5	5	4
10S416	5	5	5	5	5	5
10S424	5	5	5	5	5	5

10S425	5	5	5	5	5	4
10S430	3	5	5	5	4	4
10S435	5	5	5	5	5	5
10S439	3	5	2	5	5	5
10S440	5	5	5	3	4	4
10S442	5	5	5	5	5	5
10S444	5	5	4	5	5	3
10S461	5	5	5	5	4	5
10S469	5	5	5	5	5	3
10S477	5	5	5	5	5	5
10S479	5	5	5	5	5	5
10S497	5	5	5	5	5	5
10S502	3	3	5	4	3	3
10S504	5	5	5	5	5	5
Average	**4.7**	**4.9**	**4.8**	**4.9**	**4.8**	**4.5**

Table 62: Satisfaction survey for the Delta H_2O faucet

Keycode	Recommend faucet to others? (1=yes, 0=no, -1=not sure)	Compared to old faucet do you like new (1=more, 2 = same, 3= less, 4 = not sure)	Comments on Delta H_2O faucet
10S404	1	1	
10S407	1	1	
10S409	1	1	
10S414	1	2	Can be a bit confusing because you have to have faucet flow handle on and touch to turn on and off.
10S416	1	1	

10S424	1	1	
10S425	1	1	A little too sensitive to clean around, but the best.
10S430	1	1	
10S435	1	1	Love it - it's great. Would give it a six for ease of use.
10S439	1	3	
10S440	1	1	
10S442	1	1	
10S444	1	1	It should be a water saver.
10S461	1	1	It would be good if you could adjust the sensitivity because when I am cleaning around it, if I bump into it comes on.
10S469	-1	4	It is too easy to accidentally touch the faucet and turn it on or off. Not sure if I really like this feature.
10S477	1	1	
10S479	1	1	I wished the bathroom models were installed as well
10S497	1	1	
10S502	-1	2	Once you turn on the water, it stops by itself after flowing for a while and you have to touch it to continue - somewhat inconvenient.
10S504	1	1	Love the adjustable aerator and retractable spray nozzle

Table 63: Change in water use behavior

Keycode	Changed water use behaviors? (1=yes, 0=no, -1=not sure)	Describe changes in water use	Plan on changing or removing products? (1=yes, 0=no, -1=not sure)	Explain	Noticed reduction in bills? (1=yes, 0=no, -1=not sure)	How much has bill gone down (1= less than 5%, 2=5-10% 3=11-20% 4=21-30% 5=more than 30%)
10S404	1	Kitchen- less water running, toilets- flush water, washer - less water	-1	Bathroom aerators	-1	
10S407	1	more conscious of water use, try to use less	1	Bathroom faucet aerators	-1	
10S409	1	We are more conscious of our water use b/c we are grateful for our new fixtures/appliances	0		-1	
10S414	1	Trying to take shorter showers.	-1	Only ones we would consider moving is the bathroom faucet aerators. Spray pattern splashes easily outside of sink basin.	-1	
10S416	1	Shorter showers, turn water off more in kitchen	1	Bathroom aerators, will leave guest bath in place	-1	

		sink.		will remove from master bath. Too much splash - does not stay on long enough to wet hair in sink.		
10S417	1	Use my dishwasher more often. Have removed all grasses and have planted xeriscape shrubs. Am more aware of water waste habits.	-1		1	4
10S421	1	Use a cup when brushing teeth (rinse). Water not left on while doing other hygiene activities.	1	Will change guest bathroom to low flow aerator so as not to confuse visitors.	-1	
10S424	1	Added swamp cooler thermostats. Also more aware of needless running water from faucets	0		-1	
10S425	0		0		-1	
10S429	0		0		-1	
10S430	1	We've been a little more careful with water use, and bath faucet aerators	1	The washer is destroying our clothes and rugs and not getting them clean		

		make it easier to turn it off.		(leaving detergent in, etc.) so I can't wait to change back to the old water hog.		
10S435	0	Already pretty water conserving			-1	
10S439	1	Turn off water flow while lathering hands	0		0	
10S440	-1		-1	If it appears to save costs than will keep. Going to be hard to tell with new price increase.	-1	
10S442	1		-1	Maybe the faucet aerators.	-1	
10S444	1	Shut off kitchen faucet while soaping up.	-1		-1	
10S448	1	Shorter showers	0		1	2
10S450	-1		0		-1	
10S461	1	More aware of water use. I use car wash, don't run water unnecessarily.	1	Washing machine. There are better high efficient washers on the market.	1	2
10S465	-1		1	Bathroom faucet aerators - hard to get hot water to lavatory.	-1	
10S469	-1		0		-1	

10S475	1	Using bathroom sinks is a bit awkward, but we do use less water with the new aerators.	-1	Everything is terrific except the bathroom aerators, which takes some getting used to.	-1	
10S477	1	Trying to use less water for showers gardening and overall household.	1	The bathroom sink aerators	1	2
10S479	1	More aware - watch usage on bill more carefully.	1	Bathroom faucets/faucets	1	3
10S492	0		0		-1	
10S497	1	Attempting to use graywater, hanging clothes outside on a clothesline when able to.	0		-1	
10S502	1	Less shower time. Touch faucet in kitchen a plus when washing dishes, less water.	0		-1	
10S504	1	Composting, reduced water use for irrigation.	0		-1	
10S509	1	Miira gave us a 5 min shower timer for each timer; a dish soaking tub; food scrapers that look	0		-1	

		like spatulas. I like the way you can push off the water between rinsing dishes and compost bags.				

Appendix D: Side-by-Side Comparison of Pre- and Post-Retrofit Groups

Extrapolating potential savings from site-specific comparisons of pre-retrofit and post-retrofit water use can lead to erroneous understanding of potential savings. This is for an important reason: retrofit homes were not randomly selected; rather they were selected because they were higher than average water users. Higher than average water users would reasonably have higher than average water savings while lower water users, had they been retrofit, would likely see smaller savings.

This issue highlights the advantage of targeting retrofit programs to high water users. By identifying and focusing on higher water using sites, a water agency can maximize water conservation results. With proper targeting, these savings might be representative of savings.

Bearing in mind that these site-specific savings should not be extrapolated to the general population, comparing before and after water use can still provide an interesting picture of savings for different fixture changes. Table 64 provides a comparison of several key water use data for the 208 pre retrofit homes and 29 post retrofit homes. Figure 50 gives a comparison of indoor water use on a per-site basis. Note that in a few cases water use increased slightly, as shown by negative savings values. Table 65 through Table 70 shows the changes for indoor use, toilets, showers, clothes washers, faucets, and leaks, respectively.

Table 64: Comparisons of Pre and Post Retrofit Study Homes

Descriptive Statistics

RETO		N	Minimum	Maximum	Mean	Std. Deviation
POST	TraceLengthDays	29	10	13	12.14	.743
	IndoorGPD	29	45.4100	234.7500	100.732069	44.0792654
	Clotheswashergpd	29	.0000	80.4800	17.148276	17.1776383

Descriptive Statistics

RETO		N	Minimum	Maximum	Mean	Std. Deviation
	Dishwashergpd	29	.0000	6.2200	1.851379	1.6626479
	Faucetgpd	29	4.7200	55.4200	24.580345	11.7193011
	Leakgpd	29	.0400	61.6400	6.502759	12.8170397
	Othergpd	29	.0000	21.5200	1.062414	4.0247827
	Showergpd	29	4.4300	75.9900	26.804483	18.7232828
	Toiletgpd	29	8.8000	36.7300	19.577241	6.7718245
	Averageclotheswasherloadgal	28	10.2900	39.7000	19.426071	6.9700291
	Averageshowerseconds	29	271.6700	725.6700	483.378276	134.5616299
	Averageshowergal	29	6.3300	19.7600	12.542759	3.5356570
	Averageshowermodeflowgpm	29	1.0900	2.5500	1.584138	.2947943
	Showersperday	29	.6700	5.1700	2.058276	1.2051943
	Averagetoiletflushvolume	29	1.0400	1.9200	1.362069	.1982671
	Numberofflusheslessthan2_2Gal	29	57	291	170.48	56.530
	Numberofflushesgreaterthan2_2Gal	29	0	59	4.52	12.891
	Valid N (listwise)	28				
PRE	TraceLengthDays	208	5	14	12.68	1.011
	IndoorGPD	208	1.3000	1008.6100	137.616587	114.9473183
	Clotheswashergpd	208	.0000	107.2200	26.211298	21.5823286
	Dishwashergpd	208	.0000	10.3600	1.470000	1.8688866
	Faucetgpd	208	1.1300	130.7000	22.509712	15.9846997
	Leakgpd	208	.0000	974.8000	22.979663	100.7676114
	Othergpd	208	.0000	81.3900	1.925913	6.6854665
	Showergpd	208	.0000	107.6700	27.910625	22.1865856
	Toiletgpd	208	.0000	177.5700	31.825625	22.2842246
	Averageclotheswasherloadgal	200	6.7600	69.3200	30.515650	12.4682746
	Averageshowerseconds	202	101.4400	949.0000	474.336535	158.6854922

Descriptive Statistics

RETO	N	Minimum	Maximum	Mean	Std. Deviation
Averageshowergal	202	2.2400	43.3800	16.578416	6.3663324
Averageshowermodeflowgpm	202	1.1300	4.1600	2.121188	.5090207
Showersperday	202	.0700	8.6700	1.738317	1.2709510
Averagetoiletflushvolume	206	1.0900	5.4300	2.536214	.8677317
Numberofflusheslessthan2_2Gal	208	0	330	80.11	75.857
Numberofflushesgreaterthan2_2Gal	208	0	659	80.54	86.639
Valid N (listwise)	196				

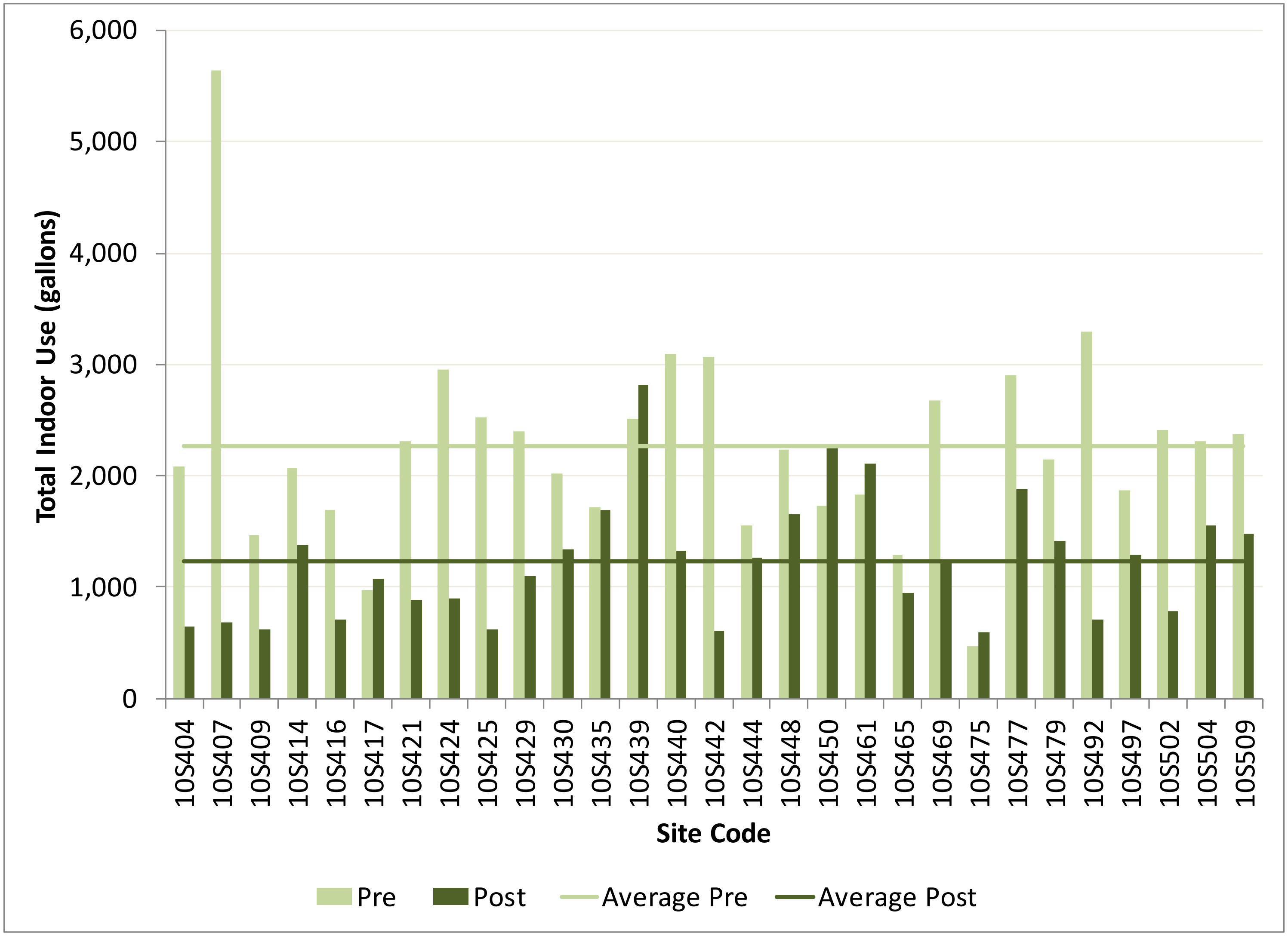


Figure 50: Comparison of indoor water use on a per-site basis.

Table 65: Tabulation of indoor water use, pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit indoor use (gal)	Post- retrofit indoor use (gal)	Savings (gal)
10S404	2,085.18	650.762	1,434.42
10S407	5,648.52	682.157	4,966.36
10S409	1,467.46	626.24	841.22
10S414	2,077.62	1375.905	701.72
10S416	1,697.21	704.814	992.39
10S417	969.83	1078.82	-108.99
10S421	2,311.85	884.619	1,427.23
10S424	2,960.22	896.801	2,063.42
10S425	2,528.41	616.591	1,911.82
10S429	2,403.35	1095.387	1,307.96
10S430	2,017.97	1344.658	673.32
10S435	1,714.85	1694.154	20.70
10S439	2,519.41	2817.002	-297.60
10S440	3,097.01	1324.995	1,772.01
10S442	3,066.42	613.973	2,452.44
10S444	1,556.62	1268.397	288.22
10S448	2,239.39	1653.182	586.20
10S450	1,736.01	2250.518	-514.51
10S461	1,828.18	2115.271	-287.09
10S465	1,286.41	951.122	335.28
10S469	2,681.09	1235.567	1,445.52
10S475	473.08	590.33	-117.26
10S477	2,902.40	1882.762	1,019.64
10S479	2,154.29	1419.652	734.64
10S492	3,291.05	715.512	2,575.54
10S497	1,875.51	1293.314	582.19
10S502	2,407.03	783.31	1,623.72

10S504	2,306.04	1555.327	750.71
10S509	2,369.99	1473.116	896.88
Average	**2264.56**	**1227.39**	**1037.18**
CI (95%)	**333.14**	**202.51**	**404.73**

Table 66: Tabulation of toilet use (in gallons), pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit toilet use (gal)	Post- retrofit toilet use (gal)	Savings (gal)
10S404	715.05	114.374	600.68
10S407	544.98	139.801	405.18
10S409	406.10	159.278	246.82
10S414	843.37	313.176	530.19
10S416	534.37	200.05	334.32
10S417	240.34	213.864	26.48
10S421	579.48	126.726	452.76
10S424	1,135.08	170.021	965.06
10S425	1,321.03	171.843	1,149.19
10S429	961.11	281.082	680.03
10S430	415.23	361.541	53.68
10S435	362.50	208.732	153.77
10S439	411.94	327.671	84.26
10S440	442.82	227.085	215.73
10S442	936.27	217.272	719.00
10S444	778.60	222.215	556.39

10S448	910.32	339.199	571.12
10S450	729.30	353.808	375.49
10S461	415.83	245.226	170.61
10S465	144.66	155.598	-10.94
10S469	455.52	258.256	197.26
10S475	108.79	120.958	-12.17
10S477	802.33	477.54	324.79
10S479	297.01	154.753	142.26
10S492	893.34	233.4	659.94
10S497	374.36	291.814	82.54
10S502	843.55	301.575	541.97
10S504	532.44	295.335	237.10
10S509	672.67	208.347	464.32
Average	**614.08**	**237.60**	**376.48**
CI (95%)	**107.20**	**31.30**	**105.76**

Table 67: Tabulation of shower use (in gallons), pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit shower use (gal)	Post- retrofit shower use (gal)	Savings (gal)
10S404	289.70	116.336	173.36
10S407	118.24	91.235	27.00
10S409	319.25	239.648	79.60
10S414	410.96	494.764	-83.81
10S416	272.60	145.694	126.91

10S417	89.48	235.965	-146.48
10S421	221.38	227.058	-5.68
10S424	858.98	211.296	647.69
10S425	376.07	126.169	249.90
10S429	10.69	53.184	-42.49
10S430	543.63	412.903	130.73
10S435	456.93	361.831	95.10
10S439	575.13	911.849	-336.72
10S440	1,006.85	235.625	771.23
10S442	721.44	125.374	596.07
10S444	187.56	552.143	-364.59
10S448	405.29	533.61	-128.33
10S450	74.47	144.607	-70.14
10S461	488.41	744.623	-256.22
10S465	155.42	154.556	0.86
10S469	316.28	399.613	-83.33
10S475	157.42	166.571	-9.15
10S477	765.42	817.001	-51.58
10S479	408.40	198.238	210.16
10S492	188.43	180.839	7.59
10S497	294.71	378.71	-84.00
10S502	446.32	173.014	273.31
10S504	577.53	362.393	215.14
10S509	777.04	672.563	104.48
Average	**397.04**	**326.46**	**70.57**
CI (95%)	**91.80**	**84.30**	**95.39**

Table 68: Tabulation of clothes washer use (in gallons), pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit clothes washer use (gal)	Post- retrofit clothes washer use (gal)	Savings (gal)
10S404	280.61	26.415	254.20
10S407	227.25	51.598	175.65
10S409	331.72	83.453	248.27
10S414	433.03	128.955	304.07
10S416	399.58	24.408	375.17
10S417	116.11	125.999	-9.88
10S421	697.63	101.794	595.84
10S424	324.89	138.269	186.62
10S425	317.28	79.396	237.88
10S429	594.80	180.146	414.66
10S430	486.55	52.534	434.02
10S435	370.75	433.268	-62.52
10S439	687.66	965.751	-278.09
10S440	994.08	434.111	559.97
10S442	664.17	88.515	575.66
10S444	292.47	241.313	51.16
10S448	134.91	235.833	-100.93
10S450	206.26	242.18	-35.92
10S461	642.97	476.651	166.32
10S465	499.47	194.071	305.40
10S469	494.53	154.401	340.13
10S475	61.88	156.477	-94.59
10S477	601.80	191.891	409.91
10S479	256.95	109.329	147.63

10S492	0.00	0	0.00
10S497	568.55	149.636	418.92
10S502	475.51	61.811	413.70
10S504	932.70	625.509	307.19
10S509	541.37	283.402	257.97
Average	**435.71**	**208.18**	**227.53**
CI (95%)	**87.46**	**75.55**	**80.77**

Table 69: Tabulation of faucet use (in gallons), pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit faucet use (gal)	Post- retrofit faucet use (gal)	Savings (gal)
10S404	265.24	266.276	-1.04
10S407	1,169.74	361.273	808.47
10S409	188.03	105.519	82.52
10S414	282.27	279.444	2.83
10S416	420.70	283.281	137.42
10S417	69.89	268.539	-198.64
10S421	561.80	297.443	264.36
10S424	617.01	323.184	293.83
10S425	468.70	218.828	249.87
10S429	363.72	253.082	110.64
10S430	495.98	403.6	92.38
10S435	419.84	664.996	-245.16
10S439	671.49	519.004	152.49

10S440	536.34	353.503	182.84
10S442	390.54	136.463	254.07
10S444	208.97	205.601	3.37
10S448	487.36	421.286	66.07
10S450	580.33	611.258	-30.93
10S461	218.77	597.475	-378.70
10S465	365.58	286.818	78.76
10S469	293.02	214.513	78.51
10S475	84.68	61.359	23.32
10S477	568.01	345.945	222.06
10S479	362.63	282.103	80.53
10S492	251.20	139.88	111.32
10S497	252.39	220.522	31.87
10S502	527.62	185.803	341.82
10S504	200.88	202.098	-1.22
10S509	244.52	184.611	59.91
Average	**398.87**	**299.78**	**99.09**
CI (95%)	**79.48**	**54.12**	**75.54**

Table 70: Tabulation of leakage (in gallons), pre-retrofit, post-retrofit and the total savings.

Site Code	Pre-retrofit leakage (gal)	Post- retrofit leakage (gal)	Savings (gal)
10S404	308.46	38.819	269.64
10S407	3,548.88	1.689	3,547.19

10S409	192.34	0.491	191.85
10S414	22.26	18.05	4.21
10S416	67.60	46.626	20.98
10S417	445.33	199.939	245.39
10S421	0.08	62.937	-62.86
10S424	0.94	0.437	0.50
10S425	20.40	20.355	0.04
10S429	44.86	43.374	1.48
10S430	0.00	6.986	-6.99
10S435	55.83	23.088	32.74
10S439	0.11	14.858	-14.75
10S440	61.26	46.977	14.29
10S442	275.65	5.814	269.84
10S444	68.51	12.887	55.62
10S448	11.41	2.094	9.31
10S450	8.92	801.379	-792.46
10S461	8.11	2.368	5.74
10S465	50.89	48.55	2.34
10S469	1,087.04	177.018	910.02
10S475	60.30	77.377	-17.08
10S477	66.27	0.522	65.75
10S479	602.72	395.884	206.83
10S492	1,755.39	13.866	1,741.53
10S497	207.10	218.282	-11.18
10S502	10.51	20.983	-10.47
10S504	15.01	42.01	-27.00
10S509	72.50	3.723	68.78
Average	**312.71**	**80.94**	**231.77**
CI (95%)	**265.23**	**59.65**	**273.56**

Appendix E: Errata

Date	Error Corrected
12/6/11	Corrected Table 32: Actual reference requirement is 51.3", or 80% of ETo. Reference demand volume of 127.9 kgal is correct.