EVALUATION OF INDOOR URBAN WATER USE AND WATER LOSS MANAGEMENT AS CONSERVATION OPTIONS IN FLORIDA

By

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To my parents, Kathie and Larry Friedman

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In several areas of Florida, alternative water supplies, reuse water, and water conservation are being considered as a means to ensure ample water can be provided in the future. In particular, system water loss and residential indoor usage estimates are two important aspects of water conservation programs which are currently based on simple approximations.

Methods tested for estimating system water loss analyzed current water audit practices as part of a water conservation plan. One approach is to use the latest version of the American Water Works Association (AWWA) audit software, coupled with the 2009 edition of the AWWA M36 handbook, which was developed to estimate water losses. The AWWA audit and M36 handbook are useful, but different performance indicators need to be used to incorporate these procedures in water conservation plans. Water loss was then analyzed as a potential quantifiable management option in Florida, showing that Florida utilities could estimate their water losses using AWWA procedures with special attention to metering all key water use components. The AWWA software Version 4.0 includes a procedure for developing a Validity Score for the audit based on the input data quality. This scoring system is reviewed and recommendations are made for a Florida specific validity scoring system.

Indoor usage methodologies for Florida were evaluated based on analyzing previous studies and test bed sites in Alachua and Hillsborough counties in Florida. Residential indoor water usage cannot be directly determined for most Florida utilities, but can be approximated based on a detailed review of end use studies that measured individual water using events. Toilets were shown to be the largest usage of indoor water in single family homes. Older homes tend to have more indoor water usage per person than newer homes due to fixture efficiency. However, newer homes use more total indoor water due to their larger size. Finally, future single family residential indoor water use patterns can be estimated based on trends in per capita water use and the expected rate at which less efficient devices will be replaced. Water utilities can accelerate this replacement rate by offering incentives to their residential customers.

CHAPTER 1
INTRODUCTION

Background

Traditional water supplies are reaching their sustainable limits in Florida. Several water stressed areas in the state are considering alternative water supplies, including reuse water, and water conservation to ensure that ample future water is provided. Although this initiative is a step in the right direction, current water conservation plans are often qualitative and do not measure how well the plan is working, or how much water was saved from implementing it.

To determine better ways to quantify the success of water conservation plans in Florida, a series of methods were tested ranging in complexity from simple to refined. A variety of methods are necessary to provide water utilities in Florida with options for creating these calculations based on the size of the utilities and the varied reasons for making the estimates. These methods will become part of software being developed by the Conserve Florida Water Clearinghouse for the purposes of water conservation planning and evaluations. The software is called EZ Guide and is described at www.conservefloridawater.org. This software is intended to allow any utility in Florida to build a water conservation plan using statewide data sources coupled with default coefficients developed from more specialized data. Utilities with other data that better reflects local condition can override default coefficients with more accurate values.

A quantitative approach toward water conservation analysis consists of three major procedures: a calibrated water budget of end uses based on recent water use data, a conservation management plan that includes a schedule for Best Management Practice (BMP) implementation, and a method for tracking actual water savings based on implementation of this plan. A conservation plan is generally developed over a 20 year time span, usually to achieve a target water savings. A water budget describes a utility's current usage patterns, and projects future usage patterns if no utility initiated conservation program occurs. Conservation planning and tracking analyze the impact that the selected conservation activities would have on water usage. These procedures can help determine whether conservation could be a cost-effective method of saving water for a utility. Implementation and tracking involves putting the conservation plan into action and recording results to test how well the plan is working.

Urban water originates at one or more sources, is transported to one or more treatment plants, treated, distributed to customers throughout the water system, and then used by the customer. A water budget typically tracks water from the point at which treated water enters a utility's distribution system to the point at which customers use water. A water budget breaks down total water supplied into various sectors of water usage. Total water supplied minimally needs to be broken down into the following sectors: single family residential, multi-family residential, non residential, and water loss. Water loss has historically been analyzed separately from other water usage sectors, using a water audit and water loss evaluation. Other sectors have typically been analyzed using end use models, which only consider water usage after customer meters, breaking down total usage into various other sectors. The water budget approach combines the water audit and end use model procedures into a single, more complete, water budget. This integration is useful since water loss can be compared directly to other sectors for conservation analysis. In addition, total supply within each sector can be broken down such as separating indoor and outdoor usage.

The water budget approach determines water usage by sector, using a production function shown by Equation 1-1. Total water usage for a utility can then be determined by summing usage for all sectors, shown by Equation 1-2. This procedure shows the relative importance of each sector and allows selection of target sectors for conservation efforts.

$$q_k = \sum_{i=1}^{m} (\alpha_i \cdot x_i) \qquad (1\text{-}1)$$

Where:

q_k = total usage for the k^{th} sector (gal/mo)
α_i = water use rate coefficient
x_i = size of water using activity
m = number of user categories within the k^{th} sector

$$q_t = \sum_{k=1}^{n} (q_k) \qquad (1\text{-}2)$$

Where:

q_t = total usage for all sectors in a utility
q_k = total usage for the k^{th} sector (gal/mo)
n = number of sectors

Conservation planning and tracking determines what areas within a given sector to target for a conservation program in a cost-effective manner, as well as how much water could be saved by implementing conservation initiatives to meet the target goal. For each sector, special bottoms-up analysis is performed to estimate the water use coefficients and the sizes of the various sectors and water use categories. The water loss and other sectors can be combined into a single conservation analysis, rather than performing two separate analyses as is common practice today.

The next step in a quantitative conservation plan consists of implementation of the selected plan that includes the proactive steps to conserve water, as well as a schedule of how much implementation is to be done per year. Tracking involves measuring before and after water usage, and recording results to determine whether the conservation plan is working. Tracking data can then be used in the budget and planning stages of future conservation analyses to improve accuracy.

Goals and Objectives

Florida's estimated gross statewide public-supply per capita water use for 2005 was 158 gal./d (gallons per day) while Florida's statewide domestic (residential) per capita water use for 2005 was 95 gal/d (Marella 2008). Thus, residential water use constitutes more than 60% of total use and indoor residential use is typically the majority of residential water use.

Accordingly, this thesis focuses on analyzing water loss and residential indoor usage as part of a conservation plan. The goal is to develop general methodologies for utilities in Florida to analyze these two components of water conservation planning. The water budget and planning aspects of water conservation are discussed. Implementation and tracking are important parts of conservation planning, but are not within the scope of this thesis.

The water loss sector as a conservation option is analyzed in Chapter 2 which analyzes current water audit methodologies and how those methods could be translated into a water budget approach for the purpose of conservation. Primary emphasis is given to the new American Water Works Association (AWWA) M36 Manual for water audits and water loss evaluations. Chapter 3 reviews the AWWA system for scoring data validity and makes recommendations for a data validity scoring system in Florida. Chapter 4 shows how a water budget approach can be used to analyze indoor water use in single family residences (SFR) in Florida. Chapter 5 discusses residential account estimates, and Chapter 6 analyzes persons per residential dwelling unit. Chapter 7 addresses per capita indoor usage rates in SFRs as well as conservation planning methodologies for indoor SFR water usage by means of selecting specific conservation initiatives for a select group of customers. Chapter 8 discusses how utilities in Florida can estimate use of water for residential swimming pools. The summary and conclusions and suggestions for further work are presented in Chapter 9.

CHAPTER 2
WATER LOSS MANAGEMENT AS A CONSERVATION OPTION IN URBAN WATER SYSTEMS IN FLORIDA

Introduction

This chapter's focus is methodologies to estimate water loss in public water supply systems in Florida as part of a water conservation plan.

Urban water originates at one or more sources, is transported to one or more treatment plants, treated, distributed to customers throughout the water system, and then used by the customer. The amount of water moving through the urban water system is measured at the source(s), the treatment plant(s), and at the delivery points to the customer. The frequency of measurement varies from hourly or daily at the master meters located at the source(s) and treatment plant(s) to typically monthly readings of customer water use. A portion of the water moving through this system may be lost or gained as measured by differences in meter readings. This chapter only addresses losses or gains in the distribution/transmission network. Because water is transported through this network under pressure, it is reasonable to assume that only losses will occur. If a gain occurs, it is due to meter errors. By contrast, wastewater collection networks typically experience gains in flows due to infiltration and inflow.

This study was initiated as part of activities of the Conserve Florida Water Clearinghouse (www.conservefloridawater.org). Water loss is a required input to the Guide software that is used to evaluate water conservation programs in Florida. A detailed description of the Guide is available at the Clearinghouse Web site. The current version of the Guide allows the user to select from several options for estimating water loss. Questions arose as to the sources of variability in these methods and whether one method is preferable to others.

The American Water Works Association (AWWA) recently published the third edition of M36, a manual of water supply practices ,titled, *Water Audits and Loss Control Programs*

(AWWA 2009). Concurrently, AWWA's Water Loss Control Committee released Version 4.0 of its Free Water Audit Software package, which can be used to compile a water audit and to evaluate water loss. This software can be downloaded from AWWA's WaterWiser Web site (http://www.awwa.org/Resources/Waterwiser.cfm?navItemNumber=1516). Earlier versions of the free water audit software have been used for water loss analysis in Florida.

Alternative performance metrics are calculated in this analysis. The question of which performance metrics are useful for Florida utilities is addressed in this chapter. Recommendations are also presented regarding ways to more fully integrate water loss evaluations within the context of overall water conservation evaluations so water loss control can be compared with other options, such as toilet retrofits. Finally, recommendations are made regarding how water loss evaluations can best be done in Florida.

Water Loss Evaluation

Water audits and water loss control have been a significant concern of the North American water industry for at least 20 years. The AWWA published the first edition of the M36 Manual of Water Supply Practices titled Water Audits and Leak Detection, in 1990. The second edition appeared in 1999 and the third edition was released in May 2009. The 2009 edition of M36 provides detailed instructions on compiling the water audit and evaluating water losses. This most recent edition incorporates much of the information found in earlier studies including Fanner et al. (2007), and Thornton et al. (2008). Water audits are done for a variety of reasons. Water balances, including audits, are essential elements of water conservation evaluations. Water loss control can be viewed as a conservation Best Management Practice (BMP) and/or measure. Water budgets for conservation planning rely on an end use analysis that partitions total water supplied into its end uses, such as toilets, showers, irrigation, etc. In this context, water loss components are viewed as an end use, e.g., pipeline losses. Also, special uses such as water provided for street cleaning can be viewed as end uses. These components are measured or estimated as part of water audits. Thus, water loss control is viewed as one of many options for managing the equilibrium of water supply and demand. Procedures for benefit-cost analysis can then be used to find the optimal blend of water conservation practices including water loss control (Chesnutt et al. (2007).

Water losses can represent a significant component of the water that is supplied by utilities to their customers. M36 focuses primarily on auditing the part of the water cycle within the network for retail transmission/distribution of treated water.. Upstream losses from the source(s) to the treatment facilities and within the treatment facilities are mentioned briefly but not addressed in detail. Similarly, losses on the customer's side of the meter are not given detailed consideration. While such losses can be significant in some systems, the primary scope of M36 is to evaluate evaluates losses in the retail transmission/distribution system.

Many regulatory agencies place upper limits on the amount of losses that a utility can incur. A popular way to represent these losses is as "unaccounted for water" (UAW) expressed as a percent of the water supplied. According to Beecher (2002), regulatory agencies in nearly all states have set upper limits on water losses ranging from 7.5% to 25% with 15% being the most common value. However, the same survey also found that tracking of actual loss levels and enforcement of these limits rarely occurs. The survey noted that an improved system of accounting for water was needed to improve accountability in drinking water utilities.

The results of a 2002 AWWA survey indicated that water loss was less than 20% for 82% of the respondents (Fanner et al. 2007). Reported water losses in the Southwest Florida Water Management District (SWFWMD) for 2007 averaged 6% with a range from 0 to 35% (SWFWMD 2009). The reported SWFWMD values seem quite low compared to national statistics. Many of the SWFWMD utilities report no losses, a physical impossibility. Florida regulatory agencies use 10-12% unaccounted for water as the upper limit on acceptable practice for water losses measured relative to finished water from the treatment plant.

Historically, a major problem with calculating losses was a lack of agreement on definition of terms in the accounting process. The AWWA Water Loss Control Committee (Kunkel et al. 2003) opposes the use of UAW expressed as a percentage of the water supplied. Instead, they advocate the term, Non-revenue Water, as specifically defined in the International Water Association (IWA)/AWWA water audit methodology included in the M36 (2009) and in the AWWA free water audit software (2009).

The water supplied to the distribution system is measured by master meters and will be referred to as Q_s. The amount of water delivered by the supply network, Q_d, is the sum of customer meter readings for all metered uses. Gross gallons per capita per day (gpcd) is a popular metric of the intensity of urban water use for the purpose of conservation evaluations. The difference between these two terms, Q_s and $Q_{d,}$, represents the amount of water lost throughout the distribution system and also the results of metering/billing error. This difference is expressed as Q_l.

In this macro view, Q_l, in units of gpcd, is calculated using Equation 2-1:

$$Q_l = Q_s - Q_d \tag{2-1}$$

Alternatively, Q_l can be expressed as a normalized percentage using Equation 2-2:

$$Q_l\ (\%) = 100*(1 - Q_d/Q_s) \tag{2-2}$$

Expressing water loss as a difference or a ratio allows policy makers to prescribe guidelines in either way. In Florida and elsewhere, water loss is expressed as a percent. For example, the goal of the draft 20x2020 Water Conservation Plan for California is to reduce statewide per capita urban water use by 20% by the year 2020 (California Water Resources Control Board 2009). However, other conservation programs express water loss goals in usage rates, e.g., reduce water use by 20 gpcd during the next 20 years.

Expressing performance using ratios and differences is an approach widely employed in the environmental and water field and in performance evaluations, in general. For example, benefit-cost analysis uses both the B/C ratio and B-C to measure the economic desirability of a project. An important attribute of performance metrics for audits is that they are based on directly measured values. Both Q_s and Q_d are measured directly by flow meters. This simple expression can be expanded to account for real and apparent gains and losses that occur within the supply network. Real losses are due to physical causes, such as leaking pipes, while apparent losses can be caused by several non-physical factors, such as errors in readings of the master meters and/or customer meters or systematic data handling error in customer billing systems. These factors are components of the various methods used to calculate water loss and described below.

The 2009 version of M36 requires several levels of auditing detail to compile the water audit and water loss evaluation. The auditing process is illustrated in Chapter 2 using an example of the fictitious County Water Company. This 57 page chapter provides detailed description of the auditing approaches to quantify components of water consumption and water loss and includes several tables that provide the quantitative basis for the entries into the water audit. Most importantly, this chapter contains supporting evidence regarding how meter reading inaccuracies were calculated. The AWWA free audit software is referenced as an appendix in the M36 and contains relatively little documentation. The software allows estimates of water use to be included without any backup information regarding how the estimates were made. We suggest acquiring the M36 Manual and the AWWA free audit software and using it as a preliminary tool (the top-down audit approach) prior to the more refined analysis (bottom-up auditing methods) detailed in Chapter 2. Results of the water loss analysis can then be used to evaluate the relative importance of controlling water loss as a water conservation option.

American Water Works Association Water Audit Method for Water Conservation Analysis

The case study on how water audits can be used as part of conservation analysis is taken from the new M36 Manual (AWWA 2009). The hypothetical utility, County Water Company (CWC), serves a population of 37,000 people. AWWA's Water Loss Control Committee advocated use of the IWA/AWWA Water Audit Method in its 2003 Committee Report (Kunkel et al. 2003). The general terms of the water balance used in the AWWA Free Water Audit Software are shown in Figure 2-1 (AWWA 2009). A water balance is used to account for the 19 sources and sinks of water as it moves through the water supply network. The values indicated in this water balance are the entries for CWC and were independently calculated to verify the results shown in M36 (AWWA 2009).

Monthly and annual water use for CWC in gallons per capita per day (gpcd) is shown in Table 2-1 for the following sectors: residential, industrial, commercial, agricultural, and water loss. The information in Table 2-1 provides a direct means of evaluating the relative importance of water losses in terms of gross gpcd. In this example, water losses account for 26% of the total water supplied of 326 gpcd. Indeed, water loss is the second largest component of the water supplied. Peak water demand is also important in urban water management. Peak water demand is 446 gpcd in August, and water losses account for 22% of water usage during that period.

These major end use categories can then be further partitioned into their components for conservation evaluations. For example, residential water use can be divided into indoor water use at 71.7 gpcd and outdoor water use of 100 gpcd. Similarly, the water loss audit partitions this component into its sub-components as shown in Figure 2-1 that shows a distribution of water uses that is focused on water losses. In a water balance, losses can be calculated as the difference between the metered water supplied and the metered water delivered. Water losses are defined differently in the M36 audit, as discussed next.

The partitioning of total water supplied into its components is shown in Figure 2-1. It is instructive to examine this water balance in order to understand its development. A more detailed description of the component terms is provided in AWWA (2009) which also includes this same example application to CWC. The AWWA water audit uses units of million gallons per year (mil. gal./yr.). The total gallons per year can be converted to gpcd by dividing by the population served. Then, Table 2-1 and Figure 2-1 can be compared directly. To maintain consistency with the AWWA reporting format, the values in Figure 2-1 are shown in million gallons per year.

The total water supplied of 4,401.4 mil. gal./yr. is simply the system input volume (3,617.7 mil. gal./yr.) plus imports (783.7 mil. gal./yr.) and minus exports (0 mil. gal./yr.). Each of these terms is measured and the values are adjusted for meter error as necessary. The 84.7 gpcd shown in Table 2-1 corresponds to the 1,143.3 mil. gal./yr. Non-revenue Water (NRW) in Figure 2-1. The customer metered billing uses are called Revenue Water (RW) and are measured directly as 3,258.0 mil. gal./yr. In this analysis, NRW is the calculated difference between two measured quantities. Revenue water is the sum of two terms, the most important of which is billed metered consumption that is the only non-zero entry in this example. Its value is 3,258.0 mil. gal./yr., the same as RW. The Billed Authorized Consumption is equal to RW. Unbilled Authorized Consumption is the sum of unbilled metered and unmetered consumption. The largest entry is for unmetered consumption, the sum of individual estimates of ten items as shown in Table 2-2. The bulk of this estimate is water use for landscape irrigation, which accounts for 162.9 mil. gal./yr. of total use. The other uses are relatively minor. The quality of these estimates can be expected to vary widely as compared to metered values. Returning to Figure 2-1, Authorized Consumption is actually the sum of metered and unmetered terms. In this case, the accuracy is still good since the majority of the authorized consumption is metered.

For water utilities just starting the auditing process and lacking detailed system data, water losses can now be determined as the residual water. Water loss equals water supplied minus authorized consumption. Water losses are the sum of apparent and real losses.

In a purely top-down approach to water auditing, the approach used in the AWWA Free Water Audit Software, apparent losses are quantified first. Next, real losses are estimated as the calculated residual, i.e., total losses minus apparent losses. Thus, real losses are not measured directly, but rather are a calculated residual, based on a combination of measured and estimated values. Also, no insight is given to the breakdown of real losses into its sub-components in the top-down, or initial, auditing approach.

Eventually, water utilities should move from a cursory, top-down approach to conduct leak detection and measure flow/pressure, to obtain information on actual leakage volumes. At this stage, the more valid measured leakage quantities should replace the cursory leakage volumes calculated as residual.

Apparent losses are the sum of unauthorized consumption, customer meter inaccuracies, and systematic data handling errors. For the initial top-down approach, the IWA/AWWA Water Audit method suggests estimating unauthorized usage as 0.25% of supplied water. Using this assumption, unauthorized usage is 11 mil. gal./yr. Systematic data handling errors are site specific. In this example, such errors account for only 21.29 mil. gal./yr. However, errors in the billing process can be considerable. Also, it is essential to first gauge the extent of data handling error since appreciable error of this kind can compromise the accuracy of volumes of customer consumption noted in the water audit.. Because customer meter inaccuracies can have a major impact on the measure of non-revenue water, the auditor must develop reliable local data on the meter stock of the utility, including performing accuracy testing on random samples of various types of meters to develop a credible estimate of customer meter inaccuracies. Procedures for estimating master meter inaccuracies are described next.

Water Meter Inaccuracies

At the utility level, one or more master meters record supplied volumes at critical points in the water distribution network. At the customer level, each residential customer has either a single meter or two meters, one for indoor and one for outdoor usage. Some uses, such as water for street cleaning, may be unmetered. Other users may have submeters which isolate the effects of certain uses such as industrial cooling water. Accordingly, a fundamental component of water loss accounting is verification of the accuracy of meter readings. Meter testing procedures and protocols exist to determine the accuracy of meter readings and a requirement for meter testing is often prescribed as a conservation measure (AWWA 1999). The meter error adjustment is an estimate of the systemic error of the meter readings. The meter adjustment, M_e, is expressed as Equation 2-3.

$$M_e = (1 + e) \qquad (2\text{-}3)$$

Where e = % error.

For example, if the meter error is +2%, then e = 0.02 and the corrected reading is 102% of the measured reading. This corrected reading is then used as the best estimate of the expected value of the meter reading.

An audit performed for the City of Las Vegas, NM revealed a master meter error of 0.2-0.7% for meters that were three years old based on manufacturer specifications (Hydrosphere 2007). Fanner et al. (2007) indicate that master meters typically have an under or over registration of 0.2-1% depending on meter age and installation procedures.

If master meter errors are random and in the range of 1-2 %, such errors would not impact the deterministic water balance that is the topic of this chapter. It is easy to include the variability in each parameter estimate and do Monte Carlo simulation if it is desired to evaluate the individual and overall uncertainty of the estimates. Errors in master meters can be either positive or negative.

While the literature suggests that master meters can have a small positive or negative error, customer billing meters are thought to have a stronger tendency to under-register (AWWA 2009). If customer meters under-register, the error in Equation 2-3 would be positive. In this case, the utilities have a stronger financial incentive to replace customer meters to increase revenue.

The City of Austin, Texas, (2006) did an audit of their 2005 water use and reported a loss rate of 15.2%. The audit estimated that under-recording customer meters was responsible for more than 25% of this loss, or 3.8% of total rate of supplied water lost.

Customer metering inaccuracies represent the collective under registration of all customer meters in a utility. Based on test studies of anonymous water utilities, typical average customer meter under registration is about 5-6% (Thornton et al. 2008). The overall extent of customer meter inaccuracies needs to be determined by local meter testing studies where the actual size distribution and ages of meters are known. The M36 Manual includes explicit procedures for estimating meter inaccuracies (AWWA 2009). These local data are essential components of a top down audit of real and apparent losses.

In the hypothetical CWC example, residential-meter losses are calculated in Table 2-3 for 5/8-inch and ¾-inch meters. These meters register 88.8%, 95.0% and 94.0% of the correct value for low, medium, and high flows, respectively. The percent time in each flow regime is multiplied by the flow rates to derive the percent of total residential flow that occurs in each flow range. This number is converted to mil. gal./yr. Finally, the meter error is calculated in mil. gal./yr. For this example, the total residential meter error is 134.3 mil. gal./yr. out of a total of 2,318.8 mil. gal./yr. Thus, the residential meters are under-recording by 5.5 percent. This answer is very close to Thornton's (2008) estimate of under-registration of 5-6%. Using similar calculations for the non-residential meters, the total customer meter inaccuracy is 164.4 mil. gal./yr. as shown in Figure 2-1.

Real Leakage Losses

The apparent losses for CWC total 196.6 mil. gal./yr. This value is deducted from the total losses of 944.1 mil. gal./yr to derive the final estimate of 747.5 mil. gal./yr. These real losses are called current annual real losses (CARL).

The IWA/AWWA Water Audit Method features several performance indicators to assess leakage standing. The best target-setting indicator expresses the CARL divided by the number of service connections in the system, and divides the resulting number by 365 to give units of gallons/service connection/day. In the CWC example, a value of 46.8 gallons/service connection/day of leakage was calculated.

The IWA/AWWA Water Audit Methodology also features a benchmarking performance indicator for real losses known as the Infrastructure Leakage Index (ILI), calculated as:

ILI = CARL/UARL, dimensionless

The UARL is defined as the unavoidable annual real losses, which is an estimate of the lower bound on real losses in the network based upon network characteristics such as the size of the system and average water pressure level (Lambert et al. 1999, AWWA 2009). UARL is estimated using Equation 2-4.

$$\text{UARL (gal./day)} = (5.41{*}L_m + 0.15{*}N_c + 7.5{*}L_p){*}P \tag{2-4}$$

Where:

L_m = length of mains and hydrant connections, miles
N_c = number of connections
L_p = length of private service piping from edge of street to customer meter, miles
P = pressure, psi

Equation 2-4 is considered to be valid for utilities with at least 3,000 connections, a minimum pressure of 35 psi, and at least 32 connections per mile of water main.

Equation 2-4 was developed by a team of international experts working under the IWA Water Loss Task Force. The database for this Equation is 27 water utilities in 19 countries (Fanner et al. 2007). UARL depends on four variables and their coefficients, i.e., the length of water mains and hydrant connections, the number of connections, the length of private service piping, and the pipe pressure.

The values of the variables needed to calculate UARL for CWC are shown in Table 2-4. The calculated value of UARL is 83.69 mil. gal./yr.

When CARL and UARL are known, the Infrastructure Leakage Index (ILI) can be calculated using Equation 2-5.

$$\text{ILI} = \text{CARL/UARL} = 47.5/83.69 = 8.9 \qquad \text{with ILI} \geq 1.0 \tag{2-5}$$

M36 suggests that utilities with relatively expensive or scarce water should operate with relatively strict leakage controls reflected by an ILI in the range of 1 to 3. Utilities with somewhat less expensive or scarce water resources could tolerate slightly higher leakage levels as denoted by an ILI value in the range of 3 to 5. An ILI value in the range of 5 to 8 can be tolerated if water is relatively inexpensive and abundant. Values greater than 8 are discouraged. Values of ILI less than 1.0 are considered to be impossible because UARL is defined as a best practice lower limit on real losses. The reader is referred to the 2009 M36 for a more complete interpretation of ILI.

Water Audit Performance Indicators

The third edition of M36 presents several water audit performance indicators. The selected subset of these indicators is presented in Table 2-5. Non-revenue water expressed as a percentage provides a direct estimate of the water loss in the system. A total of 26.6% non-revenue water indicates a system with a high level of losses. The results in Table 2-5 can be used along with Table 2-1 to evaluate the relatively important components of water use. For example, non-revenue water of 84.7 gpcd exceeds the estimated residential indoor water use of about 71 gpcd. Apparent losses are of some importance at 14.6 gpcd. Ultimately, however, a comparison is necessary to determine cost effectiveness of water-loss control relative to available options for water-demand management and other supply options.

ILI is a useful indicator for evaluating real losses but doesn't relate in any obvious way to water losses. For example, Fanner et al. (2007) calculated values of ILI and real losses, expressed as a percentage, for 17 utilities, as shown in Figure 2-2 where wide variability in the relationship between ILI and real losses is evident. Accordingly, ILI does not appear to be a good substitute for existing measures for water use regulation.

In Florida and elsewhere, regulations for water-loss control are based on a maximum allowable percent of water loss. Thus, it is still necessary to calculate this statistic along with calculating the relative importance of water loss as a portion of the gross gpcd. A system loss of 10% or greater in all parts of Florida not in the SWFWMD and 12% or greater within the SWFWMD triggers a requirement for the utility to evaluate their distribution system and fix leaks and meters until the percent loss is below this threshold.

Summary and Conclusions

The focus of this chapter is methodologies to estimate water loss in public water supply systems in Florida as part of a water conservation plan. Only losses or gains in the distribution/transmission network are addressed in this chapter. Based on this evaluation, the following recommendations are made:

- Florida water utilities should adopt the water audit and loss control procedures that are described in the 3rd edition of M36, a manual of water supply practices titled *Water Audits and Loss Control Programs* (AWWA 2009) including the water audit procedures outlined in Chapter 2 of the M36 manual. The process described in the M36 is complimented by use of Version 4.0 of the AWWA Free Water Audit Software, which offers an effective and standardized method to compile water audit data from many water utilities and conduct effective analysis of loss levels and cost impacts. Current procedures for estimating water losses in Florida are not uniform, and as a result, the accuracy of reported estimates of water loss is questionable.

- The water utility industry in North America is at the advent of implementing robust, standardized methods to assess water and revenue losses. Rather than focusing on loss reduction targets at this time, it is more important for the industry to establish standardized protocols for collection of water audit data and to carry out such data collection over a period of several years. Systematic improvement of data validity should be the primary focus of this phase of activity. Only when a sufficient pool of reliable data exists can reliable assessments of loss levels and also realistic target reduction levels be developed.

- Water loss can be viewed as a water use category as shown in Table 2-1, so that the relative importance of water loss in terms of gpcd can be accurately compared with other water uses. The cost-effectiveness of water loss control can then be compared with water conservation options and supply augmentation.

- Quantitative measures of meter accuracy are an essential part of water audits and of water conservation evaluations. Regulations regarding meters should require quantitative estimates of meter performance following accepted national procedures as described in AWWA M6, M22, M33 and M36.

- The M36 water audit method should be added to the EZ Guide as the preferred approach to evaluate water loss and conduct water audits.

- Water losses occur from the sources to the treatment facilities, within the treatment facilities and on the customer's side of the meter. In some cases, these losses might be as significant as distribution/transmission system losses. Such losses should also be considered in systems with extensive raw water transmission piping, and/or where high customer consumption suggests excessive waste occurring beyond the customer meter.

Table 2-1. Monthly and annual gpcd for four direct use categories and water losses for CWC.

Month	Residential gpcd	Industrial gpcd	Commercial gpcd	Agricultural Gpcd	Losses gpcd	Total gpcd
1	127.8	31.2	7.1	0.0	38.5	204.6
2	157.2	34.6	7.8	0.0	52.0	251.7
3	142.0	31.2	7.1	0.0	53.4	233.7
4	161.4	35.2	7.3	22.0	160.8	386.7
5	184.7	37.0	7.1	49.7	106.5	384.9
6	205.5	44.1	7.3	67.5	98.7	423.0
7	226.9	42.6	7.1	49.7	89.5	415.8
8	232.3	42.6	7.1	65.3	98.7	446.0
9	205.5	41.1	7.3	58.7	88.2	400.8
10	142.0	31.2	7.1	0.0	80.4	260.7
11	146.8	32.3	7.3	0.0	83.0	269.3
12	127.8	31.2	7.1	0.0	66.2	232.3
Average	171.7	36.2	7.2	26.1	84.7	325.8
% of total	52.7%	11.1%	2.2%	8.0%	26.0%	100.0%

Table 2-2. Sum of individual estimates of unbilled metered consumption (Adapted from AWWA 2009).

Item	Description	mil. gal./yr.
1	Fire fighting and training	9.7
2	Flushing water mains, storm inlets, culverts & sewers	2.6
3	Street cleaning	1.8
4	Landscaping/irrigation in large public areas	162.9
5	Decorative water facilities	1.8
6	Swimming pools	0.4
7	Construction sites	0.6
8	Water quality and testing	1.2
9	Water consumption at exempt public buildings	2.2
10	Other	0.9
	Total	183.8

Table 2-3. Calculated residential meter error for CWC

Flow	Residential usage, mil. gal./yr. = 2,318.8 % of Time	Avg. gpm	gpm%	% volume	mil. gal./yr.	Meter Registration %	Meter Error, mil. gal./yr.
Low	15.0%	0.75	0.11	2.0%	46.4	88.8%	5.9
Medium	70.0%	5	3.50	63.8%	1,479.4	95.0%	77.9
High	15.0%	12.5	1.88	34.2%	793.0	94.0%	50.6
Total	100.0%		5.49	100%	2,318.8		134.3

Table 2-4. General physical attributes of CWC test case

Infrastructure Data	Value
Population served	37,000
Miles of mains, L_m	250
Service connections	
Residential	11,490
Commercial, Industrial & Agricultural	706
Total connections	12,196
Average length of service connection, L_p, ft.	18
Number of fire hydrants, N_f	2,750
Average length of hydrant leads, L_h, ft.	12
Average operating pressure, psi	65

Table 2-5. Selected water loss performance indicators from the water audit

Description	Value	%
Water supplied, gpcd	325.9	100.0%
Non-revenue water, gpcd	84.7	26.0%
Current annual real losses, CARL, gpcd	69.9	21.4%
Apparent losses, gpcd	14.6	4.5%
Real losses, gpcd	55.3	17.0%
UARL, gpcd	6.2	1.9%
ILI = CARL/UARL	8.9	

AWWA WLCC Free Water Audit Software Version 4.0: Water Balance Million gallons/year				Water Audit Report For: County Water Company, Anytown, USA	Report Yr: 2006
Own Sources (Adjusted for known errors) ***3,617.7***	Water Exported ***0.0***	Billed Water Exported			
	Water Supplied ***4,401.3***	Authorized Consumption ***3,457.2***	Billed Authorized Consumption ***3,258.0***	Billed Metered Consumption (inc. water exported) ***3,258.0***	Revenue Water **3,258.0**
				Billed Unmetered Consumption ***0.0***	
			Unbilled Authorized Consumption ***199.2***	Unbilled Metered Consumption ***15.4***	Non-Revenue Water (NRW) **1,143.3**
				Unbilled Unmetered Consumption ***183.8***	
		Water Losses ***944.1***	Apparent Losses ***196.6***	Unauthorized Consumption ***11.0***	
				Customer Metering Inaccuracies ***164.3***	
				Systematic Data Handling Errors ***21.3***	
Water Imported ***783.7***			Real Losses ***747.5***	Leakage on Transmission and/or Distribution Mains ***Not broken down***	
				Leakage and Overflows at Utility's Storage Tanks ***Not broken down***	
				Leakage on Service Connections ***Not broken down***	

Figure 2-1. Results of the CWC annual audit using the AWWA Free Water Audit Software Version 4.0 expressed in million gallons per year. (Adapted from AWWA 2009).

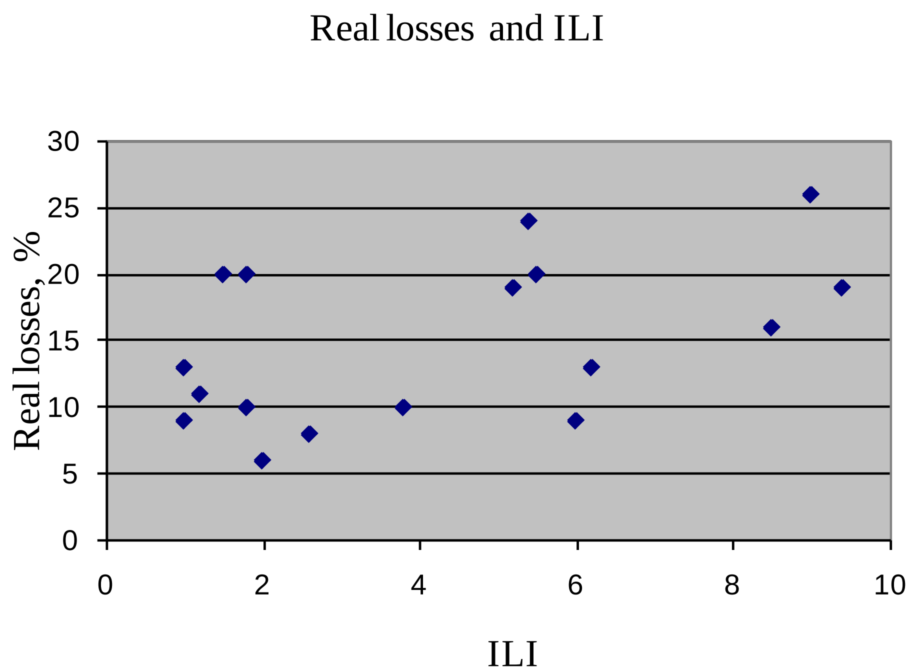


Figure 2-2. ILI versus real losses for 17 utilities. (Adapted from Fanner et al. 2007).

CHAPTER 3
VALIDITY OF WATER AUDIT AND WATER LOSS EVALUATIONS FOR FLORIDA

Introduction

Water audits and water loss control are important parts of water conservation programs. Water loss can be viewed as a water use category, so that the relative importance of water loss in terms of gpcd can be compared with other uses. The cost-effectiveness of water loss control can then be compared with water conservation options and supply augmentation. Friedman and Heaney (2009) evaluated the new, third edition of the American Water Works Association (AWWA) M36 manual, titled, *Water Audits and Loss Control Programs* (AWWA 2009a), as well as associated free software for evaluating water losses (AWWA 2009b). They recommend that Florida water utilities adopt the water audit and loss control procedures that are described in M36 including the water audit procedures outlined in Chapter 2 of the publication. They also recommend using Version 4.0 of the AWWA Free Water Audit Software, which offers a top down method to compile water audit data and analyze loss levels and cost impacts. Current procedures for estimating water losses in Florida are not uniform and the accuracy of the reported estimates of water loss is, therefore, questionable. The quality of the water audit is directly dependent upon the quality of the input data.

The AWWA software requires that the user input estimates of up to 18 parameters. The reliability of these estimates ranges from excellent for measured water uses with accurate meters to poor for unsupported estimates of unmetered quantities. The AWWA software addresses the question of the validity of the data using a weighted scoring system that provides a normalized score ranging from 0 to 100 based on the user's estimates of the quality of the data. The AWWA software includes weights for each of the 18 inputs. However, these weights are not known to the user. The relevant parameters and weights should be a function of the purpose of the audit and water loss control program. The AWWA software provides output performance estimates for four financial and six operational measures. The most relevant measure for utilities in Florida at present is the % unaccounted for water (%UAW) because this metric is used for regulatory purposes with specified upper limits of 10 to 12% UAW. However, this metric is not recommended by AWWA because of the various ways that the metric is calculated and because it only represents performance in relative terms. Friedman and Heaney (2009) suggest using %UAW and associated gallons per capita per day (gpcd) as the measures of the importance of UAW for Florida. The use of gpcd provides a measure of the importance of UAW in absolute terms.

This paper describes how a water audit can be done and how UAW or its equivalent can be calculated, following procedures outlined in the third edition of the AWWA (2009a) M36 manual and the AWWA (2009b) software. The specific focus is on how the validity of these estimates can be quantified using the procedures outlined in the AWWA (2009b) software. Thus, only the subset of the 18 parameters that deal with the water audit will be evaluated. The AWWA (2009b) software is described in the next section with emphasis on the scoring procedure. Subsequently, our evaluation of relevant procedures for Florida is presented.

Overview of American Water Works Association Water Audit Scoring Method

Friedman and Heaney (2009) present a detailed description of the AWWA water audit and the procedure for water loss evaluation. This paper focuses on the water audit component and relevant scoring methods. One new feature of Version 4.0 of the AWWA software is a scoring system to estimate the reliability of the data used to evaluate the extent of water losses and the potential cost-effectiveness of a water loss control program.

Quantitative measures of meter accuracy are an essential part of water audits and water conservation evaluations. Regulations regarding meters should require quantitative estimates of meter performance, following accepted national procedures as described in AWWA M6, M22, M33 and M36. Standardized protocols must be established for water-audit data collection, and such data collection must occur over a period of several years. Systematic improvement of data validity should be the primary focus of this phase of activity. Only when a sufficient pool of reliable data exists can reliable assessments of loss levels and realistic target reduction levels be developed.

The AWWA audit prompts the user to assign a data validity score, ranging from 1-10 for each of the 18 possible inputs in the AWWA (2009b) software with 1 denoting the poorest quality data and 10 denoting the best quality data. These 18 inputs are organized into the four major categories shown in Table 3-1.

The audit provides data quality criteria for each data validity score. A grade of 5 is given if a user selects a default value provided in the audit for certain inputs, such as unauthorized consumption. Once grades are assigned to each input, the audit calculates a composite data validity score according to Equation 3-1.

$$\mathrm{DVS} = \sum_{i=1}^{i=18} (s_i * w_i) \tag{3-1}$$

Where:

DVS = composite data validity score
s_i = user input score for input i
w_i = weighting factor for input i

American Water Works Association Scoring Ratings

Each of the 18 parameters in the AWWA Version 4.0 software has a scoring system that provides the user with 11 choices: not applicable and integer scores from 1 to 10. A brief description of the basis for each score is included. The primary parameters of interest in this evaluation are the subset that deals with metered water use or the associated meter errors. Thus, the items of interest are the following: the four categories under Water Supplied; the billed and unbilled metered under Authorized Consumption; and customer metering inaccuracies under Apparent Losses. The descriptions for three of the items under Water Supplied are the same and are shown in Table 3-2. The scoring depends on three categories:

1) percent of customers that are metered;
2) frequency of meter accuracy testing; and
3) the calibrated accuracy of the meters.

The output from the master meter error adjustment is the volume of water per year that should be added to or subtracted from the water supplied from all sources. Accordingly, this error adjustment should apply to all source master meters. The criteria for meter error shown in Table 3-3 overlap the criteria shown in Table 3-2 with regard to frequency of meter testing and meter calibration.

Similar, but not identical, scoring criteria exist for the unbilled and billed metered usage by customers as shown in Table 3-4 for billed metered usage.

Scoring for customer meter inaccuracies (#10) is presented in Table 3-5. Unlike Table 3-2, no quantitative criteria in terms of the frequency of meter testing and minimum accuracy ranges are included in the ratings.

In summary, scoring criteria are presented for the water supplied and the authorized consumption. The two basic metrics are the measured mean flow rates and the variability of these estimates. These criteria apply to all metered and unmetered components of the water audit. Water usage associated with some unmetered activities can be estimated fairly accurately if the intensities, durations, frequencies, and water use rates of the activity can be approximated. However, a more rigorous definition of unaccounted for water use would exclude all non-directly metered components.

American Water Works Association Weighting Method

The Validity Score for the AWWA method uses two metrics of importance for each of the 18 parameters: 1) an integer score from 1 to 10, and 2) a weight for each parameter based on its importance.

As discussed in the previous section, a detailed description is provided for selecting the appropriate score. However, the developers of the AWWA software have decided that the weighting procedure should not be revealed to the user. Apparently, the developers of this software are concerned that users might adjust the weights to achieve a desired score. However, we prefer to have the basis for the weights explained so that users can understand the implications of various weighting factors.

A variety of multi-attribute scoring procedures are available, and these procedures are necessarily subjective since a value judgment is made regarding the “relative importance” of each factor. Techniques from multi-attribute utility theory (MAUT) have been used to address these questions with applications to cost-effectiveness analysis, environmental impact assessments and many other areas (Keeney and Raiffa 1993). For example, Nero and Adams (2006) describe how MAUT can be applied to decision problems at Tampa Bay Water and elsewhere. A major challenge in using MAUT is having a reliable basis for assigning weights. In the case of urban water audits, a defensible method is to assign weights based on the quantity of water associated with each factor. This method is described in the proposed evaluation method presented in the next section.

Water Audit Validity Evaluation Procedure

Alternative procedures for estimating the validity of a water audit using a combination of methods contained in the AWWA software and our suggested approach are presented in this section. The basic features of this approach include the following:

- Only metered flow rates are included in the water audit. The difference between metered inputs and outputs is the unmetered water. One goal is to maximize the percentage of the water that is metered.
- The accuracy of each metered source is evaluated and reported as the extent of under or over recording for that meter. The variance of the meter readings around this mean is not relevant for this evaluation of the average performance of the meters.
- The definitions of terms from the AWWA Version 4.0 software are acceptable.
- The gross gpcd should be calculated to provide a measure of the normalized quantity of water associated with the water audit as discussed in Friedman and Heaney (2009).
- The weights associated with each factor should be assigned based on the metered flow rates for each factor rather than relying on the unknown weighting factors contained in the AWWA software.

A comparative example calculation is presented in Table 3-6. This example, includes two water supply sources, one entry for master meter error, two components of water delivered (billed and unbilled metered), and customer metering inaccuracies. These categories and associated definitions of terms are consistent with the format in the AWWA software. The entries in the Score column are user inputs following the AWWA criteria. In this example, the total score is 44 out of 60, or 73.3%. The next column is the assumed weights for this example. These weights are unknown to the user in the AWWA method and these parameter estimates are our guesses. The products of the scores times the weights are shown in the next column. The weights may be viewed as the number of times that a score is included, e.g., a weight of 20 indicates that the first score of 10 is counted 20 times. The maximum value of the score*weight is 63*10 = 630. The actual sum product is 496 so the associated score is 496/630 = 78.7% as shown in Table 3-6.

For the purposes of a water audit, the weights should be proportional to the sizes of the terms in the water audit.

The million gallons per year for each of these six elements are shown in the next column of Table 6. The total water supplied of 910 mg./yr. includes a meter error adjustment of 50 mg./yr. The total metered delivery is 750 mg./yr. leaving a total of 160 mg./yr. of unmetered water. The associated percent metered is 750/910 or 82.4 %. Alternatively, the percent unmetered water is 17.6%. These mg./yr. values can be converted to gpcd using the fact that the population served is 15,000. The resultant gpcd figures indicate a supply of 166 gpcd and unmetered water of 29.2 gpcd. (Gpcd is a popular policy metric.) In this case, the utility may face an allowable upper limit on its gpcd, e.g., 150 gpcd. Thus, the utility could reach this target by reducing their unmetered water by 16 gpcd in combination with other water conservation BMPs.

Lastly, the relative sizes of the gpcds (or equivalently the mg./yr.) can be calculated as shown in the final column. Each entry is the percent relative to the total water supplied of 910 mg./yr. (166.2 gpcd). The flow weighted score is calculated as the sum-product of the scores*flow weight or 16.0. The maximum possible score is 1.82*10 = 18.2. Thus, the flow weighted score is 88.0%.

In summary, four water audit ratings have been compared. The resulting ratings are as follows: 1) 73.3% based on the scores alone; 2) 78.7% based on the weighted scoring procedure with unknown weights; 3) 82.4% based on the proportion of the flows that are metered; and 4) 88.0% based on the flow weighted average scores. In addition, the unmetered flow is 29.2 gpcd. We recommend against using the AWWA validity score (Option 2) since the basis for assigning weights is unknown in that scoring system. A simple arithmetic average of the scores (Option 1) is also inappropriate since it does not distinguish between large and small flows. The proportion of the flows that are metered (Option 3) provides a straightforward measure of the quality of the audit. Recall that the percentage of the flows that are metered is a primary criterion in the system of scoring on the scale ranging from 1-to-10. As a result, utilities that do not meter the vast majority of their flows would have a relatively low score based on Option 3. Option 4 flow weights the scores, which addresses the question of using a quantitative basis for assigning weights, but may result in double counting to some extent.

For example, from Table 3-2, a utility receives a score of 6 if its characteristics are as shown below:

6. *At least 75% of water production sources are metered, or at least 90% of the source flow is derived from the metered sources. Meter accuracy testing and/or electronic calibration conducted annually. Less that 25% of tested meters are found outside of +/- 6% accuracy.*

In this case, the utility with 90% of its sources metered would receive a score of 6 whereas the utility is metering 90% of its flow. The question of the accuracy of these readings should be addressed in the meter error adjustment section. Thus, it appears to be redundant to do the scoring and the flow weighting. Accordingly, we recommend percent metered (Option 3) as a simple and meaningful performance measure for water audits.

Summary and Conclusions

A water audit is a fundamental first step in evaluating urban water systems. The database for this audit is recent water use data. At present, water audits are included in EZ Guide as part of the estimate of percent unaccounted for water (%UAW). In Florida, the regulatory allowable maxima for %UAW are 10 or 12. However, the utilities can calculate %UAW in different ways and are not required to support their estimates with information regarding whether the estimates are metered or unsupported guesses. Based on a detailed review of the 2009 AWWA M36 Manual on water audits and water loss, as well as the associated Version 4.0 software, we recommend estimating the validity of the water audit based on the percentage of the water supplied and used that is metered for the relative importance metric, with gallons per capita per day of unmetered water as the absolute metric of importance.

Table 3-1. Inputs for AWWA (2009) Version 4.0 Audit. (Adapted from AWWA 2009).

Number	Category	Item
1	Water Supplied	Volume from own sources
2	Water Supplied	Master meter error adjustment
3	Water Supplied	Water imported
4	Water Supplied	Water exported
5	Authorized Consumption	Billed metered
6	Authorized Consumption	Billed unmetered
7	Authorized Consumption	Unbilled metered
8	Authorized Consumption	Unbilled unmetered
9	Apparent Losses	Unauthorized consumption
10	Apparent Losses	Customer metering inaccuracies
11	Apparent Losses	Systematic data handling errors
12	System Data	Length of mains
13	System Data	Number of active and inactive service connections
14	System Data	Average length of customer service line
15	System Data	Average operating pressure
16	Cost Data	Total annual cost of operating water system
17	Cost Data	Customer retail unit cost (Applied to Apparent Losses)
18	Cost Data	Variable production cost

Table 3-2. Scoring criteria in the AWWA (2009) Version 4.0 software for Volume from own sources (#1), Water imported (#3), and Water exported (#4). (Adapted from AWWA 2009).

Grade	Description
n/a	Select this grading only if the water utility purchases/imports all of its water resources (i.e. has no sources of its own)
1	Less than 25% of water production sources are metered, remaining sources are estimated. No regular meter accuracy testing.
2	25%-50% of water production sources are metered, others are estimated. No regular meter accuracy testing.
3	Conditions between 2 and 4
4	50%-75% of water production sources are metered, others are estimated. Occasional meter accuracy testing.
5	Conditions between 4 and 6
6	At least 75% of water production sources are metered, or at least 90% of the source flow is derived from metered sources. Meter accuracy testing and/or electronic calibration conducted annually. Less that 25% of tested meters are found outside of +/- 6% accuracy.
7	Conditions between 6 and 8
8	100% of water supply sources are metered, meter accuracy testing and electronic calibration conducted annually, less than 10% of meters are found outside of +/- 6% accuracy.
9	Conditions between 8 and 10
10	100% of water supply sources are metered, meter accuracy testing and electronic calibration conducted semi-annually, with less than 10% found outside of +/- 3% accuracy.

Table 3-3. Scoring for master meter error adjustment (#2). (Adapted from AWWA 2009).

Grade	Description
n/a	Select this grading only if the water utility fails to have meters on its sources of supply, either its own source, and/or imported (purchased) water sources
1	Inventory information on meters and paper records of measured volumes in crude condition; data error cannot be determined.
2	No automatic data logging of production volumes; daily readings are scribed on paper records. Tank/storage elevation changes are not employed in calculating “Volume from own sources” component. Data is adjusted only when grossly evident data error occurs.
3	Conditions between 2 and 4
4	Production meter data is logged automatically in electronic format and reviewed at least on a monthly basis. “Volume from own sources” tabulations include estimate of daily changes in tanks/storage facilities. Meter data is adjusted when gross data errors occur, or occasional meter testing deems this necessary.
5	Conditions between 4 and 6
6	Hourly production meter data logged automatically & reviewed on at least a weekly basis. Data adjusted to correct gross error from equipment malfunction and error confirmed by meter accuracy testing. Tank/storage facility elevation changes are automatically used in calculating a balanced “volume from own sources” component.
7	Conditions between 6 and 8
8	Continuous production meter data logged automatically & reviewed daily. Data adjusted to correct gross error from equipment malfunction & results from meter accuracy testing. Tank/storage facility elevation changes are automatically used in “volume from own sources” component.
9	Conditions between 8 and 10
10	Computerized system (SCADA or similar) automatically balances flows from all sources and storages; results reviewed daily. Mass balance technique compares production meter data to raw (untreated) water and treatment volumes to detect anomalies. Regular calibrations between SCADA and source meter(s) ensure minimal data transfer error.

Table 3-4. Criteria for billed metered usage (#5) under Authorized Consumption. (Adapted from AWWA 2009)

Grade	Description
n/a	Select n/a only if the customer population is not metered, and is billed for water service on a flat or fixed rate basis.
1	Less than 50% of customers with volume-based billings from meter readings; flat or fixed rate billed for the majority of the customer population.
2	At least 50% of customers with volume-based billing from meter reads; flat or fixed rate billed for remainder. Manual meter reading used, less than 50% read success rate; failed reads are estimated. Limited customer meter records, no regular meter testing replacement. Billing data maintained on paper records, with no auditing.
3	Conditions between 2 and 4.
4	At least 75% of customers with volume-based billing from meter reads; flat or fixed rate billed for remainder. Manual meter reading used, at least 50% read success rate; failed reads are estimated. Purchase records verify age of customer meters; only very limited meter accuracy testing is conducted. Customer meters replaced only upon failure. Computerized billing records, but only periodic internal auditing conducted.
5	Conditions between 4 and 6.
6	At least 90% of customers with volume-based billing from meter reads; remaining accounts are estimated. Manual customer meter reading gives at least 80% read success rate; failed reads are estimated. Good customer meter records, limited meter accuracy testing, and regular replacement of oldest meters. Computerized billing records with routine auditing of global statistics.
7	Conditions between 6 and 8.
8	At least 97% of customers with volume-based billing from meter reads. At least 90% customer meter read success rate; or minimum 80% read success rate with planning and budgeting for trials of automatic metering reading (AMR) in one or more pilot areas. Good customer meter records. Regular meter accuracy testing guides replacement of statistically significant number of meters each year. Routine auditing of computerized billing records for global and detailed statistics; verified periodically by third party.
9	Conditions between 8 and 10.
10	At least 99% of customers with volume based billing from meter reads. At least 95% customer meter read success rate; or minimum 80% read success rate, with automatic meter reading (AMR trials underway. Statistically significant customer meter testing and replacement program in place. Computerized billing with routine, detailed auditing, including field investigation of representative sample of accounts. Annual audit verification by third party.

Table 3-5. Scoring criteria for customer meter inaccuracies (#10). (Adapted from AWWA 2009).

Grade	Description
n/a	Select n/a if the customer population is unmetered.
1	Customer meters exist, but with unorganized paper records on meters; no meter accuracy testing or meter replacement program. Workflow is driven chaotically by customer complaints with no proactive management. Loss volume due to aggregate meter inaccuracy is guesstimated.
2	Poor recordkeeping and meter oversight is recognized by water utility management who has allotted staff and funding resources to organize improved recordkeeping and start meter accuracy testing. Existing paper records gathered and organized to provide cursory disposition of meter population.
3	Conditions between 2 and 4.
4	Reliable recordkeeping exists; meter information is improving as meters are replaced. Meter accuracy testing is conducted annually for a small number of meters. Limited number of oldest meters replaced each year. Inaccuracy volume is largely an estimate, but refined based upon limited testing data.
5	Conditions between 4 and 6.
6	A reliable electronic recordkeeping system for meters exists. Population includes a mix of new high performing meters and dated meters with suspect accuracy. Routine, but limited, meter accuracy testing and meter replacement occur. Inaccuracy volume is quantified using a mix of reliable and less certain data.
7	Conditions between 6 and 8.
8	Ongoing meter replacement and accuracy testing result in highly accurate customer meter population. Testing is conducted on samples of meters at varying life spans to determine optimum replacement time for various types of meters.
9	Conditions between 8 and 10.
10	Good records of number, type and size of customer meters; ongoing meter replacement occurs. Regular meter accuracy testing gives reliable measure of composite inaccuracy volume for the system. New metering technology is embraced to keep overall accuracy improving.

Table 3-6. Comparison of methods for evaluating water audit validity.

Number	Item	Score	Assumed Weight	Score* Weight	Mil. Gal./ year	Gpcd	Gpcd Weight
	Water Supplied						
1	Volume from own sources	10	20	200	800	146.1	87.9%
2	Master meter error adjustment	3	8	24	50	9.1	5.5%
3	Water imported	10	8	80	60	11.0	6.6%
4	Water exported						
	Sub-total, Water Supplied	23	36	304	910	166.2	100.0%
	Water Delivered						
5	Billed metered	8	15	120	650	118.7	71.4%
7	Unbilled metered	8	4	32	50	9.1	5.5%
10	Customer metering inaccuracies	5	8	40	50	9.1	5.5%
	Sub-total, Water Delivered	21	27	192	750	137.0	82.4%
	Totals	44	63	496			16.0
	Maximum Value	60		630			18.2
	Relative Score	73.3%		78.7%			88.0%
	% Metered Water				82.4%		
	Unmetered gpcd					29.2	

CHAPTER 4
INDOOR WATER USAGE AS A CONSERVATION OPTION FOR URBAN WATER SYSTEMS IN FLORIDA

Traditional Approaches for Estimating Single Family Residential Indoor Usage

The vast majority of single family residential (SFR) customers within a utility have a single meter that measures their total water use, typically on a monthly basis. These meter readings are usually processed and stored in a billing database, which is the source of data for customer usage analysis. A variety of software is used for billing data and utilities may not retain these records for more than a year or two. Thus, the quality and quantity of customer billing data varies widely across utilities. Additionally, total indoor usage within the SFR sector cannot be acquired from total water usage measured by single meters at single family residences since such meter readings include indoor as well as outdoor and pool usage, as shown in Equation 4-1.

Equation 4-1 can be used at the individual customer level or any desired aggregation up to the total number of SFR customers.

$$Q_t = Q_i + Q_o + Q_p \tag{4-1}$$

Where:

Q_t = total water use (gal./mo.),
Q_i = indoor water use (gal./mo.),
Q_o = outdoor water use (gal./mo.), and
Q_p = pool water use (gal./mo.)

The minimum month method is a popular way to estimate single family indoor water usage based on total usage data (Dziegielewski and Opitz 2002). Using this method, indoor usage for a utility is estimated to be the minimum monthly usage on record. This minimum month method assumes that outdoor water use ceases in the winter because irrigation water is not needed, inferring that all metered usage in this month is indoor usage and pool use. (Pool water use continues year round even if no one is using the pool during the cooler months of the year.) The minimum month method assumes that indoor usage is constant throughout the year. A potential significant source of error in this method is that it doesn't account for the case where water use is low or zero because the customer is a seasonal resident and is not using water during some months of the year. Assuming a constant baseline indoor usage including pool usage, outdoor usage can be estimated as the residual usage using hydrograph separation, as shown by Equation 4-2 and illustrated in Figure 4-1.

$$Q_o = Q_t - Q_i - Q_p \tag{4-2}$$

Unfortunately, this approach is less valid for warmer climates, including Florida, where year round irrigation is practiced and swimming pools are popular. The minimum month of usage in Florida may still contain some irrigation and pool usage, resulting in an over estimate of indoor usage. Thus, alternative approaches need to be considered.

Process Orientated Approach for Determining Single Family Residential Indoor Usage

Monthly water use, q, in the single family indoor sector can be estimated using Equation 4-3. The simplest form of this equation consists of a single activity coefficient (α) and a single driver variable (*x*), expressed as Equation 4-3.

$$q = 30.4 * \alpha * x * n \tag{4-3}$$

Where:

q = total SFR indoor usage (gal/mo)
α = average number of people per SFR
x = average SFR indoor usage rate coefficient (gpcd)
n = total number of SFR accounts in the utility
30.4 = conversion factor from gal/day to gal/month

Equation 4-3 can be generalized to determine indoor usage for any subgroup of single family residential customers within the utility. The total indoor usage would then be the summation of the subgroup totals, as shown by Equation 4-4.

$$q = 30.4 \cdot \sum_{i=1}^{m} (\alpha_i \cdot x_i \cdot n_i) \tag{4-4}$$

Where:

q = single family residential indoor usage (gal/mo)
α_i = average number of people per home in subgroup i
x_i = average individual indoor usage rate coefficient (gpcd) in subgroup i
n_i = total number of single family residential accounts in subgroup i
m = total number of subgroups
30.4 = conversion factor from gal/day to gal/month

The number of subgroups depends on the desired disaggregation. The customers can be divided into groups based on attributes such as house size, family income, year house built, etc. Customers can also be disaggregated geographically, such as groups based on census blocks, traffic analysis zones, or political boundaries. This approach also allows for complete disaggregation of customers, analyzing the indoor usage of each individual customer. Methods for determining indoor usage for these aggregation levels will be discussed in detail in the next few chapters. Each chapter will describe how to estimate one of the coefficients at various levels of aggregation.

Description of Datasets Used to Evaluate Indoor Usage

Several datasets were used to analyze indoor usage and to determine indoor usage coefficients in Florida. Some of these datasets provide macro-scale data available to every utility in Florida, while other datasets provide micro-scale data of individual customers that are site specific and not publically available.

The combined datasets were analyzed in such a way that all recommended indoor usage coefficients could be determined using only widely available data sources coupled with default values from more specific data sources, if necessary, in the EZ Guide. If a utility chooses, the default values can be replaced by more accurate values using more detailed billing data from the utility.

For the analysis in this thesis, a test dataset called the Alachua County Test Area (ACTA) was assembled from both generally available and site specific datasets and used to evaluate indoor usage. Several datasets were used to create the ACTA dataset, shown in Table 4-1. One year of monthly residential water use data for the period from October 2007 to September 2008 for 1,402 customers who have separate regular and irrigation water meters was obtained from the Gainesville Regional Utility (GRU). Regular metered usage consists of indoor and pool usage, the total of which is the basis for wastewater charges. Irrigated metered usage consists of water used with an irrigation system and comprises outdoor residential water usage. GRU also provided monthly water use information for the same period for the remaining 29,504 residential customers who have a single meter measuring total water usage. This usage was reported by GRU as regular metered usage in the database. The monthly usage is reported in thousand gallons per month (kgal./mo.) rounded to the nearest integer. Therefore, a customer who uses less than 500 gal/mo. will be reported to have zero usage. These usages were converted to gallons per account per day (gpad). These monthly records were not adjusted to account for the date the meter was read.

In addition to the residential billing data, 2008 parcel level data was obtained from the Alachua County Property Assessor (ACPA), and similar data was obtained from the Florida Department of Revenue (FDOR). The property appraiser data differs from county to county.

However, the FDOR data are consistent for the entire State of Florida. These data sets are of high quality since they serve as the basis for water billing and property tax assessments. The ACPA and FDOR databases are updated annually and are publically available. Significant effort may be required to link the parcel level data from the utility, the ACPA, and FDOR if the utility has not already done this work. However, this link was made fairly easily for the 30,906 parcels with a single customer billing account in this dataset, since GRU provided a table that linked customer IDs in the billing database with the FDOR and ACPA databases.

Alachua County 2000 Census Block data was acquired from the U.S. Census. This data consisted of estimates of average number of people per house for each census block. Individual parcels were assigned an average people per house value based on the block that contained the centroid of the parcel. The relevant fields and attributes associated with the 30,906 parcels used in this analysis are presented in Table 4-2.

In addition to this dataset, site specific data were used to evaluate indoor usage. The American Housing Survey (AHS) contains demographic data for Tampa and Miami in reports produced about every five years. The 2007 Tampa AHS was used in this analysis (U.S. Census 2009).This study provided a distribution of people per house and described use of dishwashers and clothes washers.

Additionally, results of an extensive study on residential end uses in Tampa, conducted in 1999 and 2004 were used to help explain the end uses associated with the indoor gpcd (Mayer et al. 1999 and Mayer et al. 2004). (These uses will be discussed in depth in Chapter 7.)

Finally, a database resulting from a survey of water use in 3,537 Florida houses in 16 cities, conducted in Whitcomb (2005), was used to help determine pool usage and people per house.

Table 4-1. Description of data sets used to create the Alachua County Test Area dataset

Data Set	Source	Application	Year of Data
Monthly billing data	Utility (GRU)	Metered customer level analysis	2007-2008
Parcel geometry and Name Address Legal (NAL)	DOR	Customer level analysis	2008
Parcel subareas and extra features	ACPA	Customer level analysis	2008
Census Block	U.S. Census	Average household size	2000

Table 4-2. Definitions of fields in the ACTA dataset

Field	Data source	Definition
GRU_Reg10/2007	GRU	
GRU_Reg11/2007	GRU	
GRU_Reg12/2007	GRU	
GRU_Reg01/2008	GRU	
GRU_Reg02/2008	GRU	Monthly billed data for dual metered customers consisting of indoor and pool usage. Total billed data for single metered customers. Billed data was converted from kgal to gpad
GRU_Reg03/2008	GRU	
GRU_Reg04/2008	GRU	
GRU_Reg05/2008	GRU	
GRU_Reg06/2008	GRU	
GRU_Reg07/2008	GRU	
GRU_Reg08/2008	GRU	
GRU_Reg09/2008	GRU	
GRU_Irr10/2007	GRU	
GRU_Irr11/2007	GRU	
GRU_Irr12/2007	GRU	
GRU_Irr01/2008	GRU	
GRU_Irr02/2008	GRU	
GRU_Irr03/2008	GRU	Monthly irrigation billed data for dual metered customers only. Represents outdoor usage. Billed data was converted from kgal to gpad
GRU_Irr04/2008	GRU	
GRU_Irr05/2008	GRU	
GRU_Irr06/2008	GRU	
GRU_Irr07/2008	GRU	
GRU_Irr08/2008	GRU	
GRU_Irr09/2008	GRU	
GRU_Dual_MeterTag	GRU	Indicates a dual or single metered customer
DOR_EffYr	DOR	Year property built or year of major renovation
DOR_JustValue	DOR	The current (2008) value of a property
ACPA_HtdAreaSqFt	ACPA	The heated area of a property
DOR_Parcel ID	DOR	The parcel ID's for all parcels in a utility
DOR_Use Code	DOR	Indicates which parcels are in the single family sector
Census_ AVE_HH_SZ	U.S. Census	Average people per house value for each account based on nearest census block
ACPA_PoolTag	ACPA	Indicates whether a customer has a pool
ACPA_Beds	ACPA	Number of bedrooms within a property
ACPA_Baths	ACPA	Number of bathrooms within a property

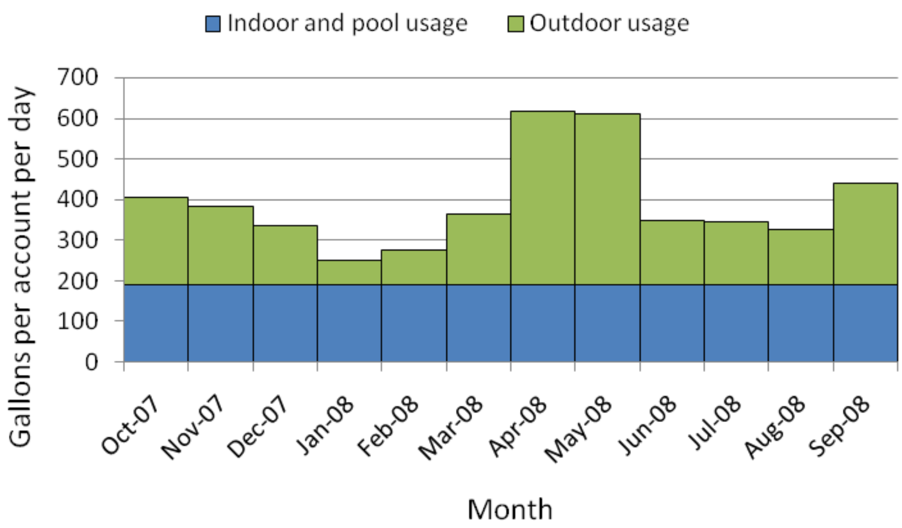


Figure 4-1. Illustrative separation of pool and indoor usage from outdoor usage

CHAPTER 5
NUMBER AND TRENDS IN SINGLE FAMILY RESIDENTIAL ACCOUNTS

Ideally, a utility billing database contains a sector classification for each account, thus allowing determination of single family accounts directly rather than having to estimate this value. A strong correlation is known to exist between number of single family accounts, and number of single family dwelling units (Dziegielewski and Opitz 2002). The number of accounts may also be estimated from the number of service connections. Accounts per sector may be deduced from this database based on relating meter size to certain sectors; however this approach introduces a source of error as it is not always a one to one relationship (Dziegielewski and Opitz 2002). Service connection information was not available from the Gainesville Regional Utiltiies (GRU) utility data. However, the publically available Florida Department of Revenue (FDOR) database can also be used to determine the total number of single family accounts based on total parcels within the utility's service boundary. For the GRU dataset, the billing database was carefully checked and 30,906 single family residential (SFR) accounts were extracted for this analysis.

The FDOR database can also be used to determine the total number of single family accounts based on total parcels within a utility's service boundary. A total of 77,560 SFR records with improvements were reported by FDOR for GRU. However, many of these records reflect multiple improvements on a single parcel, or parcels with no metered account. This data needed to be sorted so only the actual 30.906 SFR parcel accounts in the GRU service area were used in the analysis.

For the Alachua County Test Area (ACTA) dataset, the FDOR data was linked to the Alachua County Property Appraiser (ACPA) and GRU billing data sources. The total number of SFR accounts in the ACTA dataset reflect only those accounts which could be linked for all three datasets. The number of SFR accounts taken from the ACTA database was classified into the following categories:

- Total accounts = 30,906
- Duplicate accounts, or accounts that appear twice = 0
- Inactive accounts, or accounts in which no water was used during the entire year = 103

Because of the one-to-one relationship between DOR and ACPA parcels with the GRU accounts for the 30,906 customers analyzed, no duplicate accounts existed in the ACTA dataset.

Seasonality of Water Use for Single Family Residential Accounts

Seasonality of accounts was analyzed using the number of zero usage readings in the GRU billing dataset. Since usage data was recorded in units of thousand gallons (kgal.) and rounded to the nearest integer, a usage of less than 500 gal./month was reported as zero usage for that month. The number of zero months was determined for each customer in GRU, and summarized in Table 5-1. Out of the total 30,906 customers, 4,741 had at least one zero reading month. Additionally,103 customers had 12 months of zero usage, and were, as a result, considered to be inactive accounts, as mentioned previously.

The total number of zero usage values for each month is shown in Figure 5-1. The number of zero months is constant over the year of data. The average number of zero readings per month was 1,184, less than 4% of the 30,906 accounts. The results shown in Table 5-1 and Figure 5-1 suggest that relatively few customers had zero usage values that did not vary during this 12-month period.

Annual Trends in Single Family Residential Accounts

The number of SFR accounts that were added each year in the GRU service area, the total number of houses in the GRU service area, and the cumulative total number are shown in Figure 5-2. A steady increase in homes built in the GRU service area occurred from 1950 through 1975, and then dropped off to less than 600 single family homes built per year from 1985-2007. In

2007, the total number of GRU SFR accounts was 30,906. Assuming that the amount of houses built per year in GRU is only affected by the past few years of data, it can be assumed that the constant rate of 600 houses built per year in GRU will continue in the future. Therefore, the total number of single family residential accounts in GRU is predicted to increase by 600 each year over a conservation planning period of 20 years. Thus, the projected number of SFR accounts in GRU can be estimated using Equation 5-1.

$$\text{SFR accounts} = 30{,}906 + 600*(t-2007) \tag{5-1}$$

where t = 2007, 2008,… 2027

Future SFR accounts can also be estimated based on projected population growth for the utility. Utility population projections can be obtained from the master plan for the city. The Bureau of Economic and Business Research (BEBR) at the University of Florida makes population projections for cities throughout Florida. Also, the state's five water management districts project population in a variety of ways. The problem with using these projections to estimate a utility's number of SFR accounts is that the boundaries of the city and the boundaries of the utility service area may differ. This limitation can be overcome by combining utility service area boundaries with FDOR, CTA, and U.S. Census parcel databases in GIS. GIS coverages of utility service area boundaries can be obtained from Florida water management districts. These coverages for the Southwest Florida Water Management District (SWFWMD), the St. Johns River Water Management District (SJRWMD), and the South Florida Water Management District (SFWMD) can be downloaded at the respective web links: From SWFWMD at http://www.swfwmd.state.fl.us/data/gis/, from SJRWMD at http://www.sjrwmd.com/gisdevelopment/docs/themes.html, and from SFWMD at http://www.sfwmd.gov/portal/page?_pageid=2894,19708242,2894_19708955&_dad=portal&_sc

hema=PORTAL. The Suwannee River Water Management District (SRWMD) and the North Florida Water Management District (NFWMD) did not have utility service area boundary coverages available at the time of this analysis.

A value for people per house can be determined for each parcel within a given utility. These parcel estimates can then be summed to arrive at a current population, with future projected population dependent on available parcels within the service boundary. Determination of people per house is discussed in the next chapter.

Final Recommendation for Number of Single Family Residential Accounts

The number of accounts will change and likely increase over the conservation planning horizon. However, the rate of change of number of accounts is site specific depending on factors such as land availability and the health of the local economy. Since number of houses built per year and the number of accounts can be analyzed easily by any utility in Florida using a statewide database, it is recommended that utilities enter their customers' house year built information into the GUIDE, creating a figure like Figure 5-2. Next, a forecast algorithm can be created to predict future number of houses built per year based on recent trends.

Table 5-1. Customers with zero usage months in ACTA

Number of zero usage months	Number of customers
1	2,248
2	794
3	419
4	280
5	218
6	153
7	118
8	106
9	89
10	64
11	149
12	103
Total	4,741

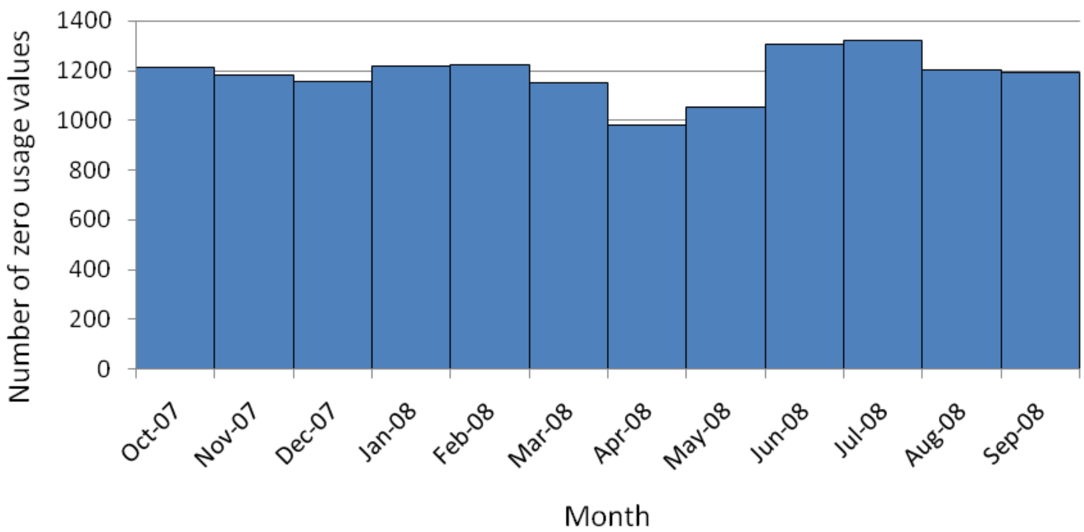


Figure 5-1. Number of zero usage values per month out of 30,906 SFR GRU accounts.

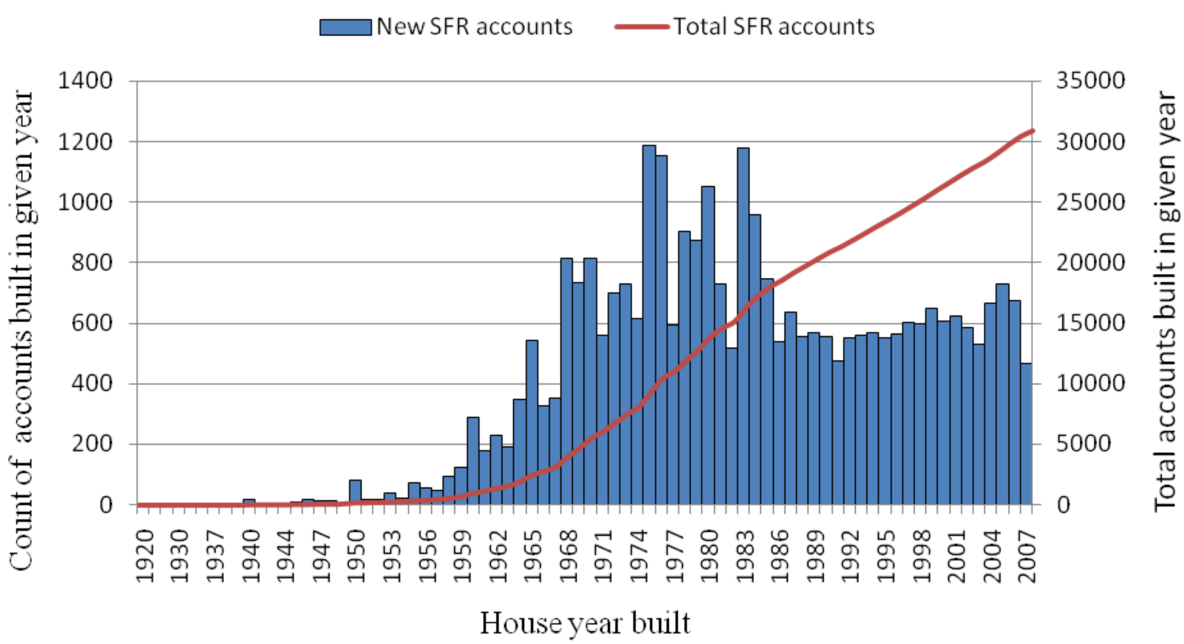


Figure 5-2. Count of SFRs built each year and the total number of SFRs served by GRU.

CHAPTER 6
PEOPLE PER HOUSE

People per single family residence (SFR) can be evaluated at an aggregate or individual customer level. Various methods of determining system wide as well as individual people per SFR are discussed in this chapter.

Determination of Number of People per Single Family Residence

Housing data, including average people per house within a given boundary, is generally acquired through customer surveys. Most utilities do not directly acquire housing data and therefore planners must rely on other sources to determine average number of people per SFR . Two major sources of housing data within the Unites States are the U.S. Census and the American Housing Survey (AHS), which is conducted by the U.S. Department of Housing and Urban Development (HUD) along with the U.S. Census Bureau.

The U.S. Census conducts a country wide mail survey every 10 years at the individual parcel level to document many attributes of the nation’s population, including housing data. The survey results are grouped in various levels of aggregation ranging from census blocks to country wide averages. However, the U.S. Census aggregates on political and spatial boundaries, and does not consider boundaries of utility service areas. In addition, the U.S. Census does not distinguish single family from multi-family residences in its average people per house calculations at any aggregation level. As a result, a census block can range from a few residences in rural areas to several thousand residences in urban areas with many apartment buildings. Census blocks generally follow city blocks in urban areas but may be much larger in rural areas. These factors must be taken into consideration when using U.S. Census data to estimate utility-wide people per house estimates for SFRs.

Updated housing data is available from the U.S. Bureau of the Census for all urban areas every 10 years, and data from the U.S. Census can be accessed directly from the U.S. Census Web site, http://www.census.gov/, as direct tables or as Geographic Information System (GIS) shape files. Direct tables are available for political boundaries such as cities, counties, and states. The GIS shape files contain census-block information at the county level, the smallest aggregation at which average number of people per household is available from the U.S. Census.

In addition to the census, HUD along with the U.S. Census Bureau, conducts American Housing Surveys for selected cities at the individual parcel level (Dziegielewski and Opitz 2002). Data from the the American Housing Survey (AHS) is available for three Florida cities: Miami, Orlando, and Tampa. AHS data for Miami are available for 1975, 1979, 1983, 1986, 1990, 1995, 2002, and 2007. AHS data for Orlando are available for 1974, 1977, and 1981. AHS data for Tampa are available for 1985, 1989, 1993, 1998, and 2007.

The AHS is conducted by representatives who directly interview residents. Survey results are then raised proportionally until the estimate of total number of homes match the value from the most recent U.S. Census count of homes. This estimation assumes that housing units not included in the survey are similar to those actually surveyed. The survey results, which include estimates of the number of residents per household, are reported as aggregated values for various subgroups of the population. The AHS does include an average household size for SFRs only (U.S. Census 2009).

No direct housing survey has been performed by Gainesville Regional Utilities (GRU). Therefore results of the 2007 AHS of Tampa, as well as the 2000 U.S. Census data for the City of Gainesville and Alachua County, and the survey data generated by Whitcomb (2005) were used to estimate the probability density function (pdf) of persons per house for GRU at the individual parcel level. The various estimates of people per house pdfs for GRU were used to determine statewide procedures for determining people per house pdfs which can be implemented for utilities in the EZGuide.

Determination of Single Family Residential People Per House Using 2007 American Housing Survey Data

The 2007 AHS of Tampa reports number of people per house as shown in Table 6-1. The distribution of this data is shown in Figure 6-1.

For SFRs in the Tampa AHS, people per house values are reported as discrete integers ranging from one through seven or more people per house. The sample size for AHS is individual houses; thus, this survey provides a good way to estimate actual variability in persons per house. From this report, the Tampa-St. Petersburg area had an average of 2.31 people per SFR home with a standard deviation of 1.28.

Determination of Single Family Residential People Per House Using 2000 U.S. Census Data

Data on people per SFR house were available from the U.S. Census for Alachua County, which coincides somewhat with the GRU service area boundaries. This data is available as a county wide average and directly displayed on the U.S. Census website. At the census block level, the data is available in GIS shapefiles, which can be downloaded from the U.S. Census Web site or from the Florida Geographic Data Library (FGDL).

Alachua County had an average of 2.34 people per household based on the countywide average available on the U.S. Census Web site (U.S. Census 2007). The State of Florida had an average of 2.46 people per home based on the 2000 U.S. Census (U.S. Census 2007). These averages include both single family and multifamily homes.

The U.S. Census provides average people per house values for each census block in Alachua County, as well as for other counties. This information is available as GIS shapefiles for the 2000 Census (U.S. Census 2007). For the purposes of this study, these census files were combined with utility boundaries in GIS to determine the 291 census blocks that are in GRU. This resulted in a range average of 0 to 9 people per home in GRU with an average of 2.41 people per home with a standard deviation of 1.06. A pdf and cumulative density function (cdf) of this information is shown as Figure 6-2.

Much overlap existed between the FDOR parcel boundaries and census block files in GIS therefore making it difficult to determine which GRU accounts belonged to the various census blocks. Each account was assigned to a census block based upon which census block the centroid of their parcel boundary included. The number of GRU accounts per census block varied from 1 to 1,377 with an average of 106 and a standard deviation of 182. A total of 133 out of 30,906 SFRs in GRU were assigned to a census block which had a zero people per house value.

The average people per house value for GRU SFR accounts based on accounts being assigned to census blocks was 2.53 with a standard deviation of 0.42. A normal distribution was fit to these estimates for GRU as shown in Figure 6-3.

Distribution of People Per House Using Whitcomb 2005 Data

Whitcomb (2005) evaluated the effects of price on water use in SFRs in Florida. This study included a survey of 3,537 customers in 16 cities which included people per house data for 3,407 accounts, shown in Table 6-2. The pdf and cdf of people per house for this survey are shown in Figure 6-4. An average of 2.50 people per house with a standard deviation of 1.23 people per house was observed for this dataset.

Distribution of People Per House Using Gainesville Regional Utilities Dual Metered Customer Indoor Billing Data

Direct monthly indoor usage data from 10/2007-9/2008 was available for 1,402 dual metered SFR customers in GRU. For each customer, an average indoor usage as gallons per account per day was determined from the monthly data. Assuming 70 gallons per capita per day (gpcd) of indoor water usage, the number of people per house can be determined by Equation 6-1, which can be derived from Equation 4-3. (The justification for the 70 gpcd assumption will be discussed in detail in Chapter 7.)

$$\alpha_i = q_i / x_i \tag{6-1}$$

Where:

α_i = number of people per house for customer i
q_i = average gpad for customer i
x_i = SFR indoor usage rate coefficient (gpcd) for customer i

This analysis resulted in an average of 2.54 people per house with a standard deviation of 1.61 for GRU's dual metered customers. The pdf and cdf of this data are shown in Figure 6-5.

Comparison of Persons Per House Distributions

The GRU census block, GRU dual metered customer, Tampa AHS, and Whitcomb (2005) individual persons per household distributions are compared in Table 6-3 and Figure 6-6. The people per house estimates based on GRU census block data showed much less spread than the GRU dual meter estimates. This difference is due to census block average values being assigned to individual homes, with several hundred homes possibly receiving the same people per house value. Although the spread was different for these estimating techniques, both have an average of about 2.5 people per house. The Whitcomb (2005) people per house values appear to follow a lognormal distribution, with an average of 2.5 people per house, but with a different standard deviation than either GRU estimate. The coefficients of variation for Whitcomb (2005) and 2007 Tampa AHS data were about 0.5, which represent the two studies with parcel level people per house estimates.

Annual Trends in People per House

Annual trends in people per house were analyzed for the 30,906 GRU customers. A plot of people per house as a function of the year that the house was built was used to evaluate possible trends as shown in Figure 6-7. A slightly increasing trend was shown with year house built; however number of people per house did not vary significantly over time. People per house values were not compared to household size since household size and year house built were correlated. This relationship is explained in more detail in Chapter 6. People per house can be assumed to be constant over time in Florida based on this analysis.

People per House Recommendation

Based on the detailed GRU analysis, people per house follows a lognormal distribution with a mean of 2.5 people per house. Although the average number of people per house is around 2.5 for GRU, the average may vary among utilities. However, the coefficient of variation of people per house for Florida may be consistent with the Whitcomb (2005) and Tampa AHS 2007 data, with a value of 0.5.

The recommended procedure for evaluating people per house for a utility in Florida follows below. (A more detailed explanation of determining a lognormal people per house distribution is shown in Appendix A.)

- Obtain GIS census block data for the county in which a utility service area is located
- Obtain utility boundary GIS files from water management district(s) to determine census blocks for the utility
- Assign a census block people per house value to individual FDOR parcels within utility service area based on the centroid of the parcel
- Determine the number of unoccupied homes
- Determine from occupied homes the average and standard deviation people per house values
- Assume a lognormal distribution for people per house values with the parameters determined

Once people per house along with number of SFR accounts are known, the population or size of a utility can be calculated. Once size is known, the water usage coefficient for a utility needs to be calculated to determine SFR indoor water usage. Indoor water usage for SFR is analyzed in Chapter 7.

Table 6-1. 2007 Tampa American Housing Survey reported number of people per single family residence. (Adapted from U.S. Census 2009).

Persons/SFR	Count 1,000s	%	Variance	Variance	St. Dev.
1	328.9	30.6%	1.71		
2	394.5	36.7%	0.09		
3	144.7	13.5%	0.48		
4	133.5	12.4%	2.87		
5	53.6	5.0%	7.25		
6	12.6	1.2%	13.64		
7	7.2	0.7%	22.02		
Total	1,075				
Average		2.31		1.65	1.28

Table 6-2. People per single family residence data for 16 Florida cities. (Adapted from Whitcomb 2005).

City	Sample size	Average pph	St. Dev. pph	COV pph
City of Lakeland	221	2.19	0.87	0.40
City of Melbourne	253	2.58	1.15	0.45
City of Ocoee	244	2.45	1.12	0.45
City of St. Petersburg	273	2.52	1.10	0.44
City of Tallahassee	213	2.00	0.68	0.34
City Of Tampa	257	2.32	1.08	0.46
Escambia County Utilities	222	2.36	1.08	0.45
Hillsborough County Utilities	220	2.44	0.84	0.35
Indian River County Utilities	197	3.15	1.98	0.63
Miami Dade	139	2.52	1.14	0.45
Palm Beach County	234	2.50	1.15	0.46
Palm Coast City	282	3.20	1.48	0.46
Sarasota County Utilities	257	2.58	1.21	0.47
Seminole County Utilities	155	2.48	0.94	0.38
Spring Hill	179	2.27	1.49	0.66
Toho Water Authority	61	1.79	0.84	0.47
Total	3,407	2.50	1.23	0.49

Table 6-3. Comparison of various methods to determine people per single family residence in Florida

Parameter	GRU census block averages assigned to individual customers	GRU dual meter customer average	Whitcomb (2005) customer average	2007 Tampa AHS customer average
Count	30,906	1,402	3,407	1,074,900
Mean	2.53	2.54	2.50	2.31
Std. dev.	0.42	1.61	1.23	1.28
COV	0.167	0.634	0.492	0.554

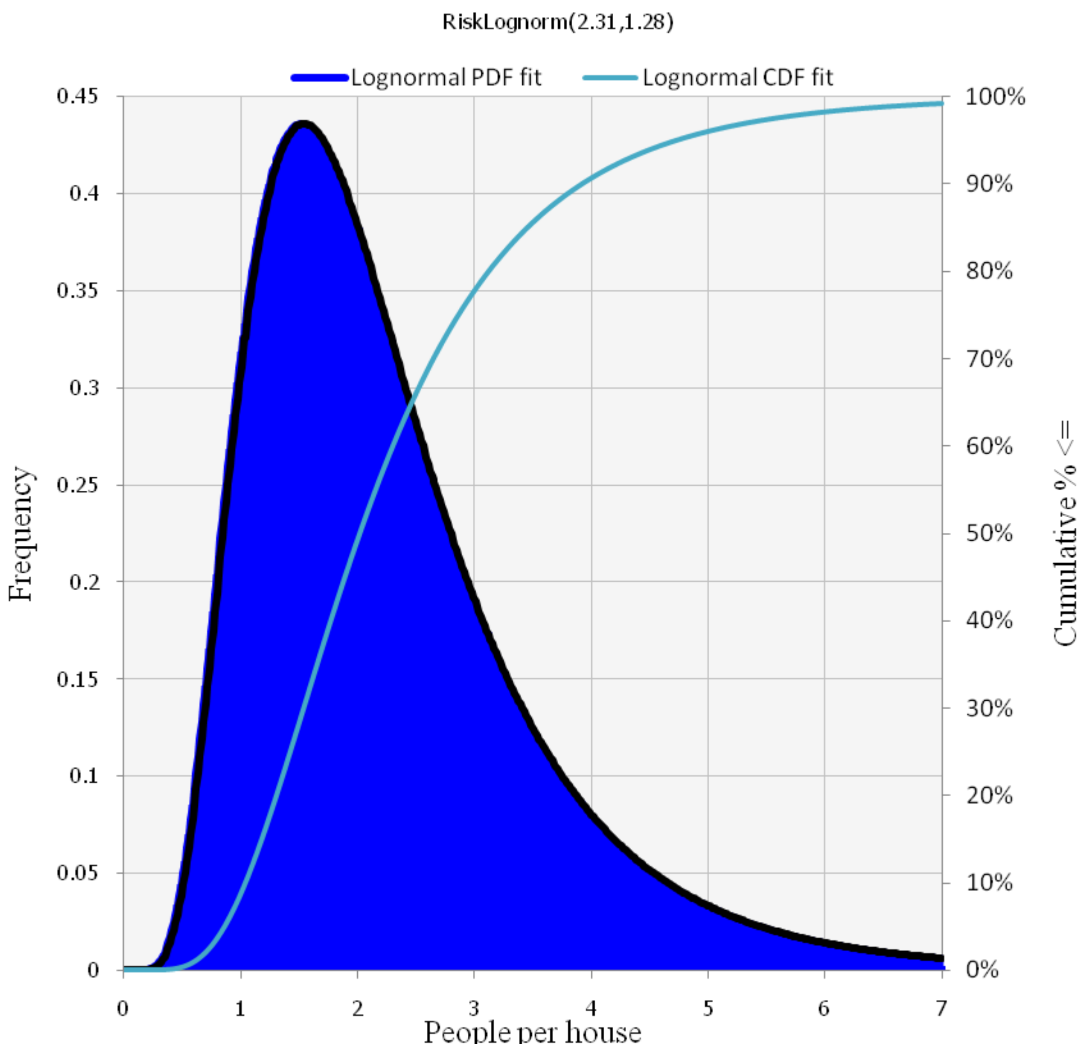


Figure 6-1. People per house distribution for 2007 AHS Survey of individual residences in Tampa, Florida

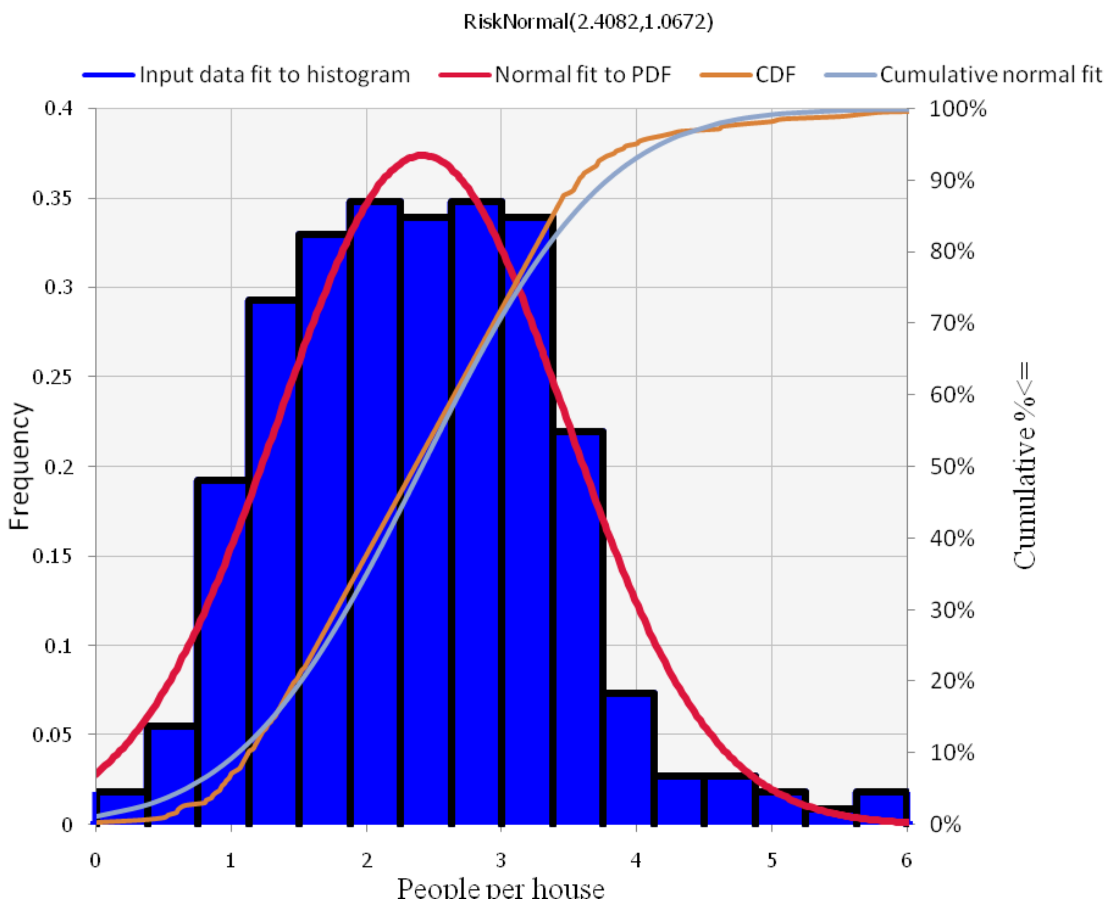


Figure 6-2. People per house distribution for 291 GRU 2009 Census Blocks

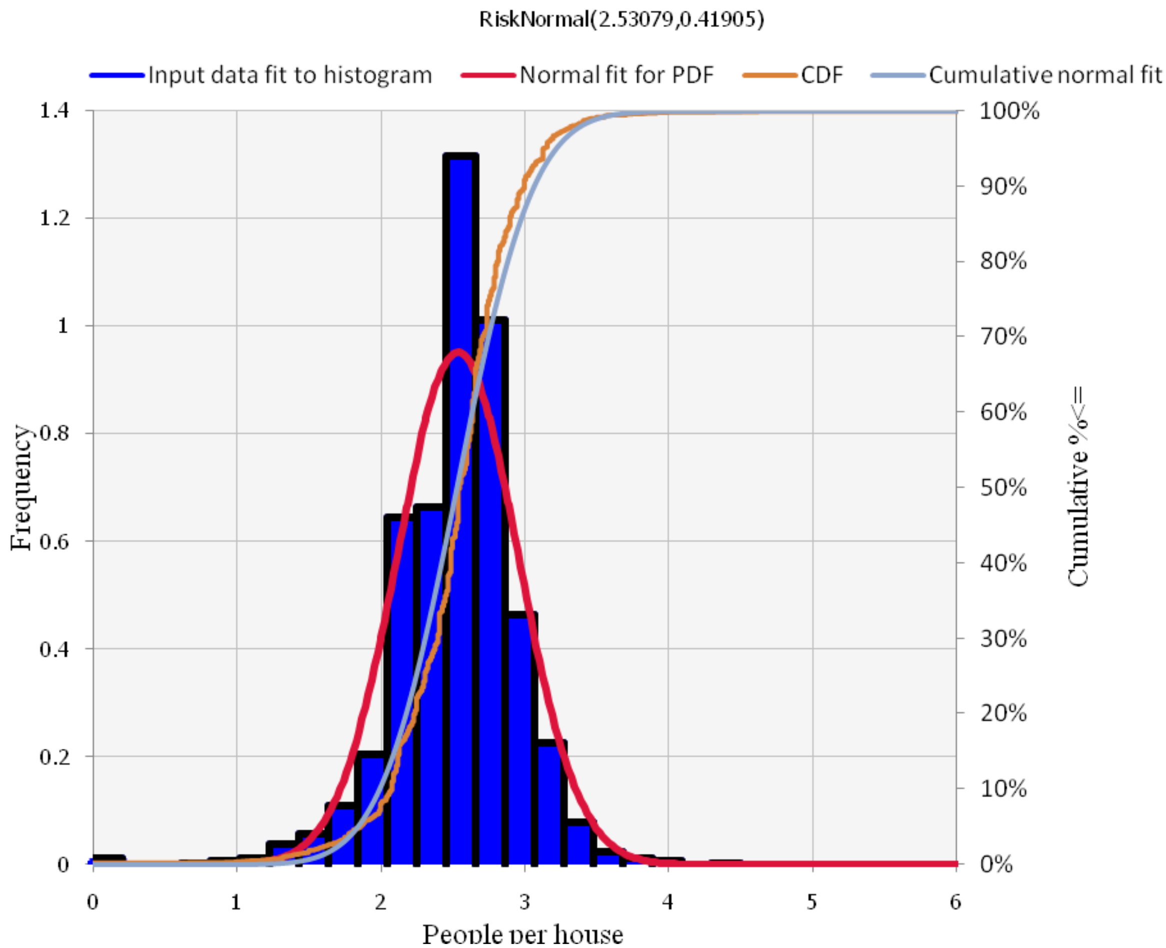


Figure 6-3. Normal distribution of census block based on people per house for 30,906 SFRs in GRU

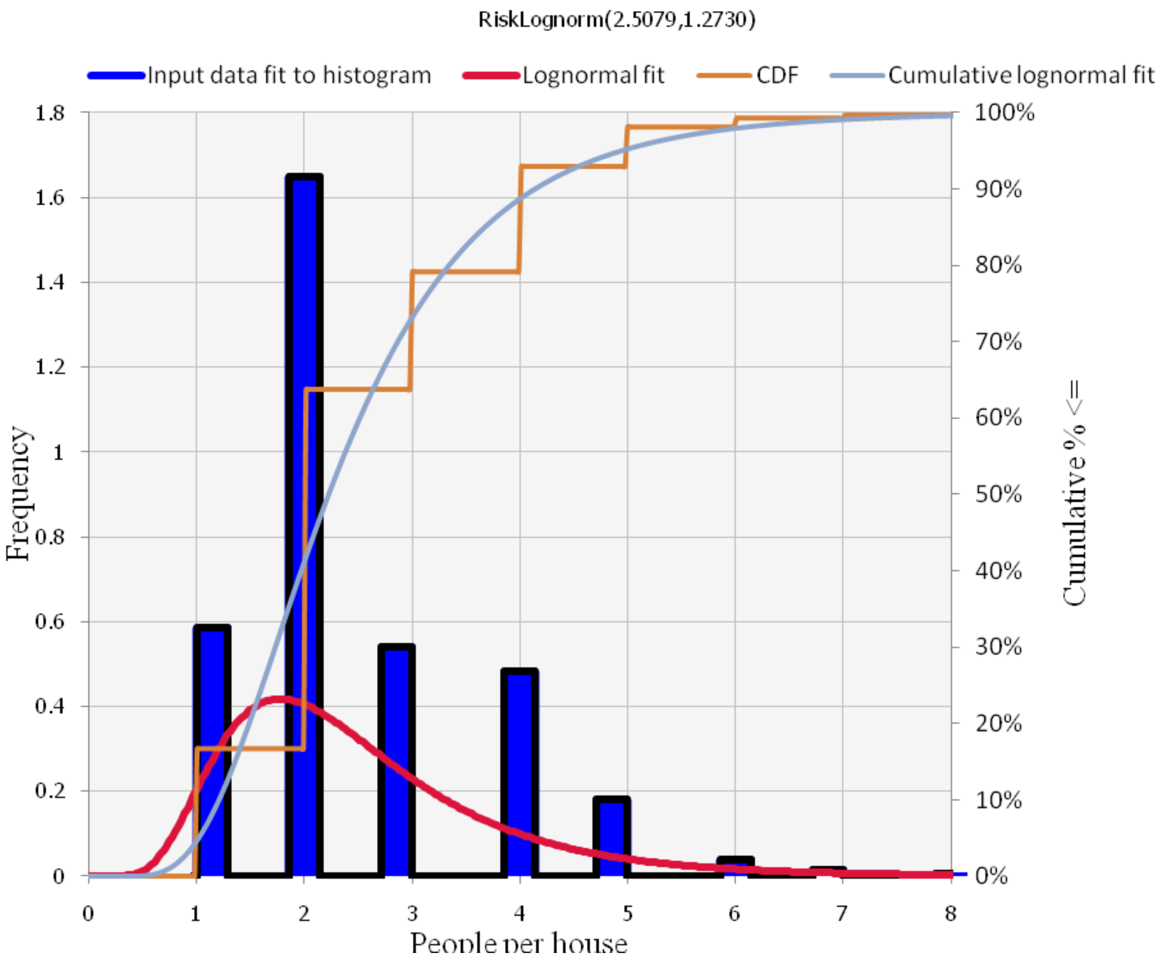


Figure 6-4. People per house distribution for 3,407 SFRs in 16 Florida cities. (Adapted from Whitcomb 2005).

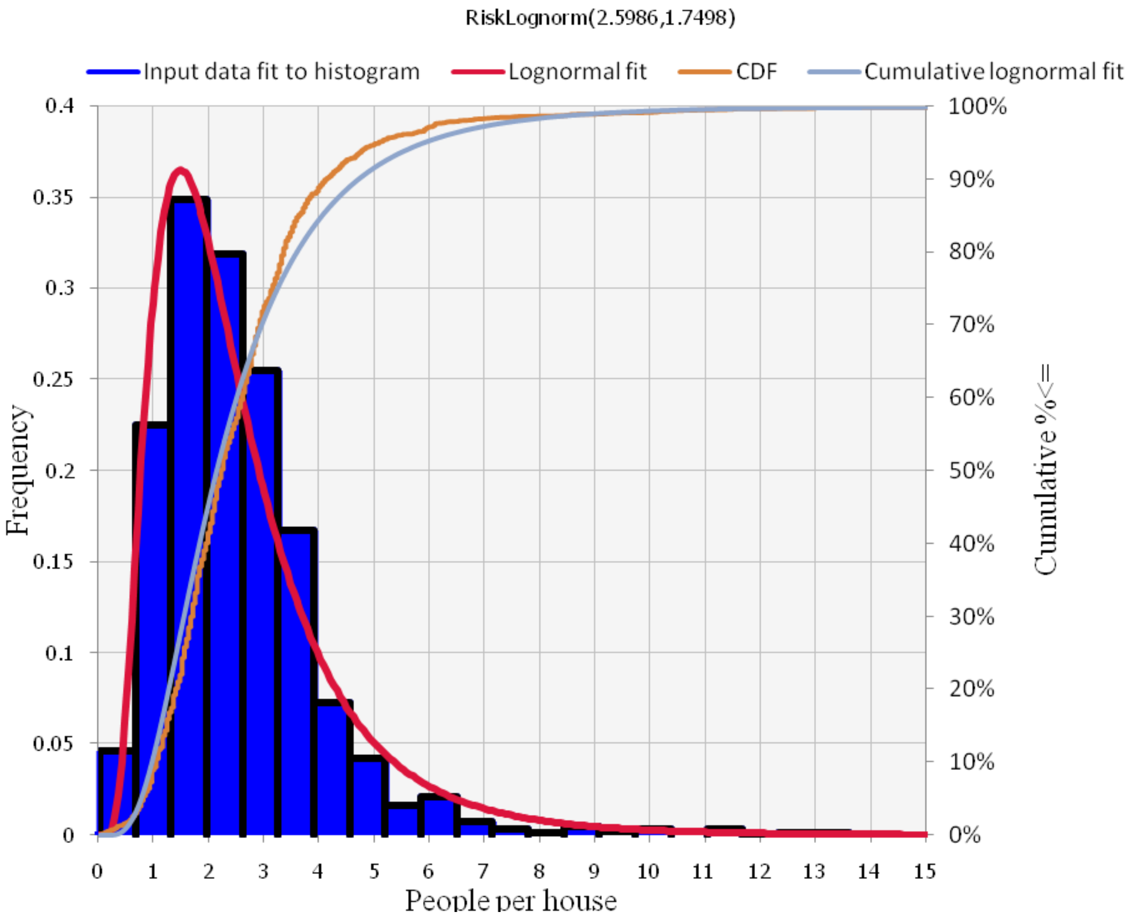


Figure 6-5. Lognormal distribution of people per house values for 1,402 dual metered homes in GRU based on indoor water use of 70 gpcd

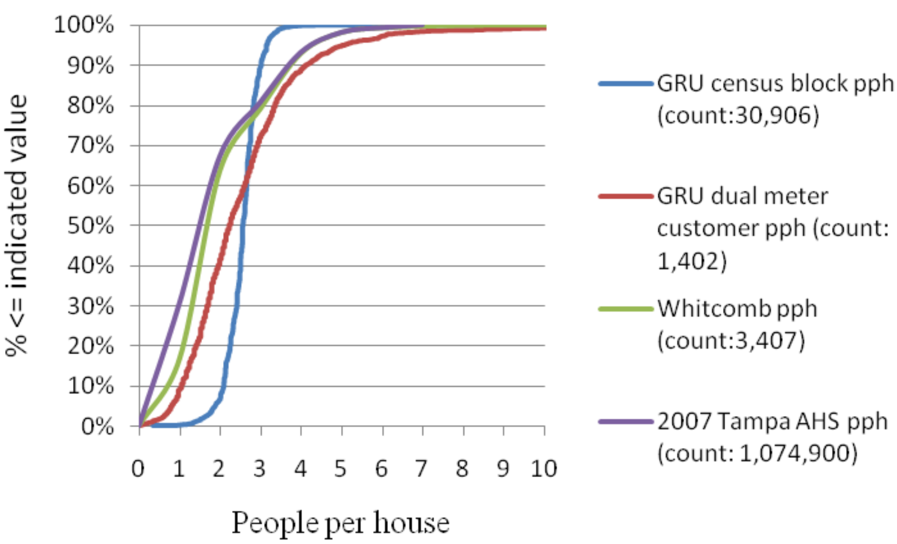


Figure 6-6. Comparison of four people per house cdfs

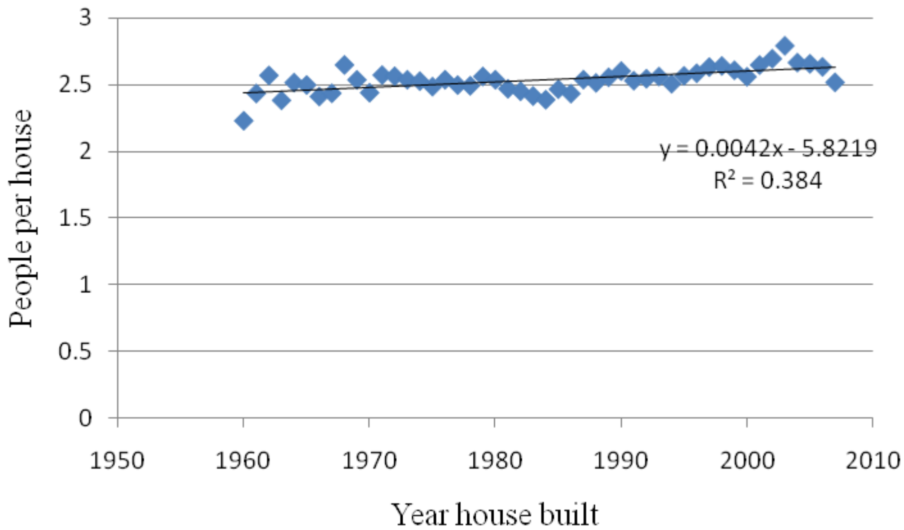


Figure 6-7. People per house vs. year house built for all GRU customers

CHAPTER 7
INDOOR WATER USE PATTERNS FOR SINGLE FAMILY RESIDENCES

The average gallons per capita per day (gpcd) can be determined at the individual customer level using a process oriented approach known as an end use analysis. Based on this approach, the total indoor gpcd of any given customer is the sum of all the indoor usage components shown in Equation 7-1. The system-wide gpcd would then be the average of all individual gpcd values, as expressed by Equation 7-1.

$$x = (1/n) \cdot \sum_{i=1}^{n} (t_i + s_i + f_i + l_i + b_i + cw_i + dw_i + tr_i + o_i) \qquad (7\text{-}1)$$

Where:

x = average individual indoor usage rate coefficient (gpcd)

n = total number of single family residential customers in the utility

t_i = toilet usage for customer i (gpcd)

s_i = shower usage for customer i (gpcd)

f_i = faucet usage for customer i (gpcd)

l_i = leakage after customer meter for customer i (gpcd)

b_i = bath usage for customer i (gpcd)

cw_i = clothes washer usage for customer i (gpcd)

dw_i = dishwasher usage for customer i (gpcd)

tr_i = water used for treatment for customer i (gpcd)

o_i = other indoor usages for customer i (gpcd)

A detailed study of single family gpcd in 12 North American cities was conducted by Mayer et al (1999). Approximately 100 homes were monitored in each of the 12 cities. This study used direct end use measurements for each house for two periods: two weeks in a warmer month and two weeks in a colder month to acquire the detailed gpcd information shown in Table

7-1. A process oriented approach was used to estimate individual water using events such as toilet flushes by developing signatures for each water using activity (DeOreo, Heaney, and Mayer 1996). Then, software called Trace Wizard was used to classify the ten second water use data into end uses. Based on this table, the indoor gpcd was consistently around 70 gpcd for all cities, including Tampa, Fl with 65.8 indoor gpcd. The average persons per house of 2.8 also appeared to be fairly consistent across the 12 cities. The effectiveness of water conservation Best Management Practices (BMPs) such as using newer toilets with less gallons per flush was estimated in Mayer et al. (1999) by doing cross-sectional analysis of houses with different types of fixtures.

While the results of this national study showed strong evidence that the newer fixtures saved water, a more definitive experimental design would be to monitor the same house before and after it was retrofitted. This more complete longitudinal analysis was done in a follow-up study of a subsample of about 30 houses in three of the original 12 cities (Mayer et al. 2005). Only indoor water use was monitored in the follow-up retrofit study. This study logged homes for two weeks using 10 second high frequency data. After the initial two week data logging, each of the 25-30 homes in each city was retrofitted with new, water efficient devices for indoor water use. Then, these same houses were logged again a few weeks after the installation and then again six months later. All three monitoring periods were two weeks in duration. The resulting water use patterns observed in the three cities are shown in Table 7-2. The average indoor gpcd and breakdown of end uses compared well to the 1999 study. This indoor retrofit study presents the most direct evidence of the savings from replacing older fixtures with new ones. This study showed that toilets and leaks were the largest end use components, accounting for almost half of the total indoor water usage. This study showed that baseline indoor gpcd of around 70 gpcd can be dropped to around 40 gpcd by installing retrofits (Mayer et al. 2005). It appears that most leaks are a result of inefficient or malfunctioning toilets, therefore making toilets the largest contributor to indoor water usage. The results of these two studies are used to estimate indoor water use trends as described next. Results from all three cities in the retrofit study were used to estimate indoor water use trends in Florida, since indoor usage patterns and retrofit results were similar among the three cities studied.

Fixture Usage Trends

Table 7-2 shows that indoor gpcd can be reduced with more efficient fixtures. Aquacraft Inc. (2005) discusses in detail the fixture types, efficiencies, and water savings for the houses that were retrofit and compares the results to other retrofit projects. While this study provides recent data on fixture usage, it does not describe trends in fixture efficiency over time. Mayer et al. (1999) presents a detailed summary of temporal trends in water use per fixture. This data has been evaluated by Vickers (2002) as well as several others to analyze fixture usage trends. Metcalf and Eddy, Inc. (1975) and Brown and Caldwell (1984) provide fixture usage and indoor gpcd trends in the United States for the 1970's and 1980's.

Metcalf and Eddy, Inc. (1975) provides a detailed end use breakdown of single family homes before 1975, shown in Table 7-3. A total 63 gpcd was reported although leaks were not considered in the end use analysis, and no data on fixture type or fixture usage intensity were reported.

Brown and Caldwell (1984) conducted a detailed residential end use study in the early 1980's which included the effects of conservation. Shower usage for 162 households, toilet usage for 196 households, and clothes washer and dishwasher usage for 181 households were analyzed. Faucet usage, bath usage, and leakage were estimated as well as the number of toilet flushes per day. The sample of households selected was newer, average sized, homes with above average income levels. For each end use, households were classified as non-conserving, intermediate, or conserving, based on fixture type. Non-conserving households were then retrofitted with water conserving fixtures to determine potential water savings. The results of this study are shown in Tables 7-4 to 7-7 for non- conserving households, intermediate households, conserving households, and all households respectively. Brown and Caldwell (1984) does not directly state how many households were in each category for each end use, although the report states that 46% of participating households had water saving shower heads or shower flow restrictors, and 33% of households had water saving toilets or devices to reduce toilet flush volume. Brown and Caldwell (1984) showed an average indoor usage of 66.2 gpcd for the homes studied with 77.3 gpcd for the non-conserving group. These values are less than pre 1980 indoor gpcd estimates from Mayer et al. (1999), mainly due to lower values for fixture usage intensity presented in Brown and Caldwell (1984) and shown in Table 7-8. Mayer et al. (1999) assume constant usage intensity over time. However, Brown and Caldwell (1984) suggest that fixture usage may have been less in the early 1980's, particularly in terms of number of flushes per day and shower duration. Brown and Caldwell (1984) suggested that conserving homes had more leakage than non conserving homes, which is an unexpected result. This result is probably attributable to the small sample size of homes tested for leakage, as well as to intrusive sampling methods. Brown and Caldwell (1984) mentioned that only 13 low flush toilets were tested for leakage.

Based on these studies, fixture trends over time and fixture savings rates were determined for the major indoor end uses described in Equation 7-1 (toilets, showers, faucets, clothes washers, and leakage). Minor end uses, such as dishwashers, are also discussed in this section. Three historical periods were selected:

- Pre-1980 representing water use before significant attention to demand management
- 1980-1994 representing a period of changing water use patterns and some improvements in water use patterns
- 1995-present representing the current period after water demand management options have been implemented, e.g., the 1.6 gallon per flush toilets.

SFR per capita water use is the weighted average of the % of SFRs in each category times the average gpcd for each category.

Toilet Usage

For toilets, the largest indoor usage component, improvements in toilet technology have reduced use rates from about5.0 gallons per flush (gpf) before 1980 to 3.5 gpf in the 1980-1994 period, and down to 1.6 gpf beginning in 1995 as shown in Table 7-9.. A constant rate of toilet use of 5.1 flushes per person per day was observed in Mayer et al. (1999) as well as Aquacraft Inc. (2005). This value of 5.1 flushes per person per day is assumed to be the same for all three periods. Consequently, toilet use per capita is simply the product of gallons per flush*flushes per day or 25.5, 17.9, and 8.2 gpcd, for the three periods. Indoor usage savings (gpcd) from toilet retrofits can be determined based on toilet transitioning from the older to newer states as shown in Table 7-10. Accordingly, the savings rates range from 0 to 17.9 gpcd.

Showerhead Usage

Showerhead water use with time is shown in Table 7-11. Three major time periods existed in which the efficiency of showerheads changed. Aquacraft Inc. (2005) suggested that 1.75 gallon per minute (gpm) showerheads were being installed in newer homes. This study also showed a constant shower use intensity of 0.7 showers per person per day for eight minutes per shower. Shower usage savings based on improved fixture efficiency is shown in Table 7-12. Most homes in the Aquacraft Inc. (2005) study had 2 gpm showerheads retrofitted to 1.7 gpm models.

Faucet Usage

Faucet water use for the three periods is shown in Table 7-13. Aquacraft Inc. (2005) suggested that 1.0 gallon per minute (gpm) faucets were being installed in newer homes. Mayer et al. (1999) suggested each person uses faucets for 8.1 minutes per day. Faucet usage savings based on improved fixture efficiency is shown in Table 7-14. Most homes retrofitted in the Aquacraft Inc. (2005) study were retrofitted to 1.0 gpm faucet models.

Clothes Washer Usage

Clothes washer water use for the three periods is shown in Table 7-15. Clothes washers in new single family residential (SFR) homes were front loading horizontal axis models which used 27 gallons of water per load. The three city retrofit study, as well as Mayer et al. (1999), show a constant average of 0.37 clothes washer loads per person per day. Savings in clothes washer usage based on improved fixture efficiency is shown in Table 7-16. Most homes in the Aquacraft Inc. (2005) study were retrofitted to 27 gallon per load front loading horizontal axis clothes washers.

Leakage

Leakage after the customer meter can be analyzed as a SFR indoor water end usage, since this kind of leakage is excluded when evaluating system losses. Leakage rates in SFRs with time are shown in Table 7-17. The residential end use study described in Mayer et al. (1999) as well as the retrofit study described in Aquacraft Inc. (2005) showed that leakage was a significant indoor usage, at 9.5 and 12.4 gpcd respectively. Although this kind of leakage increased over time based on these two studies, higher leakage rates were expected since older homes were selected for retrofit. Therefore, it can be assumed that houses pre 1980 had a leakage rate of around 12.4 gpcd. Assuming leakage will continue to decrease at a constant rate, an average leakage value of around 11 gpcd was expected between 1980 and 1995.

Dishwasher and Other Indoor Usages

Dishwasher water use for the three time periods is shown in Table 7-18. Mayer et al. (1999) show that a constant average of 0.1 dishwasher loads per person per day is used. Water savings in dishwasher usage resulting from improved fixture efficiency is shown in Table 7-19. Since dishwashers constitute only about 1.4 percent of total indoor water usage, they were not considered for retrofit in the Mayer et al. (2005) study.

Other indoor uses, such as baths and water treatment, also constitute a small percentage of total indoor water use and should not be a consideration for retrofit. No savings rates are therefore provided for these end uses. Based on Mayer et al. (1999) and Aquacraft Inc. (2005), these other uses contribute about four gpcd toward overall SFR indoor usage.

Summary of Fixture Usage Trends

For all fixtures, the water use has decreased over time, and the intensity of usage (such as showers per person per day for showerheads) was shown to be constant with time. Toilets and faucets yield the most potential savings, in gpcd, by replacing old fixtures with new ones. In addition, retrofitting toilets may yield even greater savings than suggested in Table 7-10 since leaks are a significant end use associated with inefficient toilets. Dishwashers yield the least savings per retrofit.

Number of People Using a Fixture

The savings from retrofitting fixtures also depends on the number of persons using a fixture. Retrofitting frequently used fixtures should result in more savings than retrofitting less used fixtures. The number of people using a fixture within a given SFR home can be determined based on people per house and the quantity of a given fixture in a home, expressed by Equation 7-2.

$$d_i = \alpha / f_i \tag{7-2}$$

Where:

d_i = fixture demand or number of people using fixture i
α = people per house
f_i = quantity of fixture i within a given home

In Chapter 4, people-per-house values were determined using census block data for every parcel in GRU. To determine the quantity of various fixtures within a given home, the fixture stock for all customers in GRU was determined.

Gainesville Regional Utilities Fixture Stock

The number of toilets, faucets, showerheads, clothes washers, and dishwashers was determined for all GRU customers. Other water using fixtures, such as baths, known to contribute small amounts of indoor water use were not determined.

The number of toilets, faucets, and showerheads per house was determined from the number of bathrooms per house for all customers in GRU according to Table 7-20. This determination assumes that all whole bathrooms have one toilet, faucet, and showerhead and all half bathrooms have a toilet and faucet. All homes were assumed to have one faucet in the kitchen. The number of bathrooms was known from the Alachua County Property Appraiser (ACPA) data, as explained in Chapter 3. Since property appraiser data varies from county to county, a utility may not be able to determine number of bathrooms per house and, therefore the fixture stock of the homes in the utility. The distribution of number of bathrooms in GRU is shown in Table 7-21. This table shows that, as of 2007, most homes in the GRU service area have two bathrooms.

The number of clothes washers and dishwashers for GRU could not be directly determined. Therefore, Tampa-St. Petersburg American Housing Survey (AHS) data for 1985, 1989, 1993, 1998, and 2007 were used to estimate the number of clothes washers and dishwashers in GRU. The percentage of SFRs with these appliances is shown in Table 7-22.

Most SFRs in Tampa-St Petersburg had clothes washers, ranging from 86% in 1985 to 95% in 2007. Dishwashers have increased in popularity from 51% of SFRs having a dishwasher in 1985 to 75% in 2007 (U.S. Census 1985, 1989, 1993, 2000, 2009). Based on this information, it was assumed that all SFRs in GRU had a clothes washer. Dishwasher fixtures were not determined for GRU, since dishwashers represent a small portion of indoor water usage.

Distribution of Number of People Using a Fixture in Gainesville Regional Utilities

Once the fixture stock was determined, the number of people using various fixtures could be determined for all SFR customers in GRU, using Equation 7-2. A probability density function (pdf) and cumulative density function (cdf) of the number of people per toilet for GRU is shown in Figure 7-1. The distribution was lognormal for GRU with an average of 1.29 people per toilet and a standard deviation of 0.49. Similar distributions could be created for faucets and showerheads since all three of these fixtures were based on the number of bathrooms.

Trends in Number of People Using a Fixture

Larger, newer homes may have more fixtures due to the size of the house, but with about the same number of people using these fixtures. To test this assumption, trends in number of people using a fixture with year house built as well as with heated area were analyzed. Before determining these relationships, the correlation between year house built and heated area needed to be determined to assess possible correlation between these two variables. For all SFRs in GRU, year house built was plotted as a function of heated area as shown in Figure 7-2. This figure shows a fairly strong positive relationship between year house built and heated area, with an R^2 of about 0.80. Thus, trends in the number of people using a fixture need to be analyzed. These trends were evaluated using year house built data that is publically available for all of Florida from the Florida Department of Revenue (FDOR) database.

Based on Equation 7-2, trends for the number of people using a fixture depends on the number of people per house and the number of fixtures with year house built. From chapter 4, Figure 4-5 showed that people per house is relatively constant with time. Therefore, trends in number of people per fixture can be expressed as a function of year built.

For all GRU customers in SFRs, the number of people per toilet was plotted in Figure 7-3 as a function of year house built. This figure shows the number of people per toilet decreasing linearly with year house built; a finding that suggests that larger, newer, SFRs have more toilets per house since people per house was about constant. Similar trends were observed for faucets and showerheads.

Trends in the number of bathrooms with year house built can be used to analyze trends in the number of toilets, faucets, and showerheads per house. The number of bathrooms and year built for all 30,906 GRU customers in SFRs were known from this dataset as shown previously. Distributions of the number of SFRs built with a given number of bathrooms for the years 1960 through 2005 in five year intervals are shown in Figure 7-4. This data is shown as normalized percentages in Figure 7-5. Most SFRs from 1960-2005 were built with between one and three bathrooms, with few homes having more than three bathrooms. Most homes built before 1960 were one bathroom homes. Between 1960 and 1980, the number of bathrooms in homes steadily increases from one to two bathrooms with three bedroom homes starting to appear. Between 1980 and 2000, two bathroom homes continued to dominate and three bathroom homes increased in popularity. By around 1990, 1 bathroom homes were seldom built. After 2000, 2 bathroom homes have started to decline, while 3 bathroom homes have increased in popularity. This data show a trend in newer, larger, homes having more bathrooms.

The cumulative number of SFRs in GRU with a given number of bathrooms for the years 1920 through 2005 in five year intervals is shown in Figure 7-6. This data is shown as normalized percentages in Figure 7-7. Based on the recent data, it can be expected that over the next 20 years construction of three bathroom houses will increase, and construction of two bathroom houses will decrease with one bathroom houses seldom being built.

This information suggests that older, smaller, homes should be targeted for retrofits since these homes have fewer toilets per person and use more water per flush. This strategy would replace older, less efficient, fixtures which are used more frequently, saving the most water possible per dollar spent on retrofits.

Trends in Base Replacement of Fixtures

Base replacement refers to an individual SFR customer replacing an old fixture with a more efficient fixture without any utility incentive. If no replacement occurred, the indoor gpcd of a house would be directly proportional to house age, since homes are required to be built with current fixtures based on plumbing codes. For example, a home built before 1980 would have all pre 1980 fixtures such as a 5 gal/flush toilet and a 3.3 gal/min faucet for an infinite time period. A home built before 1980 with inefficient fixtures could use more than 100 gpcd for an infinite time period based on these assumptions. Likewise, a home built after 1995, in which the most efficient fixtures have been installed, such as 1.6 gal/flush toilets and 1 gal/min faucets, would use around 45-50 gpcd indoors based on the fixture efficiency values shown previously. Customers have a wider range of choices for clothes washers and may opt to not purchase the more water efficient options.

Pre 1980, homes can be assumed to have had older fixtures. After 1980, however, newer homes were built with more efficient fixtures, thus causing the overall system indoor gpcd value to decrease. Eventually, older homes will retrofit to newer fixtures, further decreasing system wide indoor gpcd. Indoor gpcd would be overestimated if base replacement was not taken into consideration.

The 1999 residential end use study, combined with the GRU dataset were used to analyze the base replacement of fixtures in GRU. The 1999 end use study (Mayer et al. 1999) provides a representative, detailed end use analysis with an overall 69.3 indoor gpcd, shown in Table 7-1. All SFR accounts in GRU were broken down by year house built, into either the pre-1980 group, the 1980-1994 group, or the 1995-2007 group, shown in Table 7-23. GRU services an older community, with 42% of SFRs in its service area built before 1980 and 75% built before 1995.

Without base replacement of indoor fixtures in SFRs within the GRU service area, fixture efficiency would be proportional to the house age breakdown. In such a scenario, 42% of SFRs in GRU would have the least efficient indoor water fixture models. Another 33% would have moderately efficient models, and 25% would have the most efficient models. The average gpcd in the GRU service area for the four main fixtures; toilets, showerheads, faucets and clothes washers was determined and compared to actual, measured indoor gpcd values from the 1999 residential end use study, shown in Table 7-24. The GRU calculated gpcd, assuming no base replacement, is greater than the 1999 end use study for all four major fixtures, with showers and faucets showing the most difference. Base replacement must occur in GRU since the gpcd estimates for GRU assuming no natural replacement were higher than measured values.

The natural replacement for each of the four fixtures was determined using an optimization algorithm shown in Figures B-1 through B-4. This algorithm replaced various percentages of the old and moderately efficient fixtures with new fixtures until the calculated GRU gpcd matched the measured value from the 1999 end use study. The predicted efficiency distribution for these four fixtures is shown in Table 7-25. The average annual base replacement rate of low and medium efficiency fixtures to high efficiency fixtures can be calculated by Equation 7-3. The annual natural replacement rates for these four fixtures in SFRs in the GRU service area are shown in Table 7-26.

$$BR = \left(\frac{P_o - P_m}{P_o}\right) \cdot \left(\frac{1}{y_f - y_i}\right) \tag{7-3}$$

Where:

BR = average annual base replacement rate (%)
P_o = percent of accounts with fixture assuming no base replacement
P_m = percent of accounts with fixture using modeled base replacement algorithm
y_f = most recent year analyzed for base replacement of fixtures
y_i = initial year base replacement of fixtures could occur

Faucets and showerheads showed significant base replacement while toilets and clothes washers did not. This data support the recommendation that toilets be retrofitted first, since old toilets were shown to not be replaced often.

Final Recommendation for Single Family Residential Indoor gpcd

Based on the results of this chapter, it appears that SFR customers use an average of 70 gpcd, and this estimate can be applied throughout the United States. In addition, it was shown that older homes tend to have less efficient fixtures which are used more frequently than newer homes, even though extensive faucet and showerhead retrofits have taken place in older homes. Also, houses with up to date appliances could reduce their indoor water usage per person from 70 to 40 gpcd.

Summary of Single Family Residential Indoor Usage Coefficient Recommendations

The summary of recommended coefficients for single family residential indoor usage is shown in Table 7-27. These recommendations are designed for any utility in Florida to use for creating a 20 year conservation plan.

Table 7-1. Water use statistics from 1999 Residential End Uses of Water Study. (Adapted from Mayer et al. 1999).

City	Sample size	Persons/ house	Toilet gpcd	Clothes washer gpcd	Shower gpcd	Faucet gpcd	Leak gpcd	Other gpcd	Bath gpcd	Dish washer gpcd	Total indoor gpcd
Seattle	99	2.8	17.1	12.0	11.4	8.7	5.9	0.0	1.1	1.0	57.1
San Diego	100	2.7	15.8	16.3	9.0	10.8	4.6	0.3	0.5	0.9	58.3
Boulder	100	2.4	19.8	14.0	13.1	11.6	3.4	0.2	1.4	1.4	64.7
Lompoc	100	2.8	16.6	15.3	11.1	9.9	10.1	0.9	1.2	0.8	65.8
Tampa	99	2.4	16.7	14.2	10.2	12.0	10.8	0.3	1.1	0.6	65.8
Walnut Valley WD	99	3.3	18.0	14.1	11.7	12.3	7.6	2.3	1.0	0.8	67.8
Denver	99	2.7	21.1	15.6	12.9	10.5	5.8	0.5	1.6	1.2	69.3
Las Virgenes MWD	100	3.1	15.7	16.8	11.4	11.2	11.2	1.1	1.3	0.9	69.6
Waterloo	95	3.1	20.3	13.7	8.3	11.4	8.2	6.0	1.9	0.8	70.6
Phoenix	100	2.9	19.6	16.9	12.5	9.6	14.8	2.2	1.2	0.8	77.6
Scottsdale	99	2.3	18.4	14.5	12.6	11.2	17.6	5.0	0.9	1.1	81.4
Eugene	98	2.5	22.9	17.1	15.1	11.9	13.6	0.1	1.5	1.4	83.5
Average	99	2.8	18.5	15.0	11.6	10.9	9.5	1.6	1.2	1.0	69.3
St. dev.	1.4	0.3	2.3	1.6	1.9	1.1	4.4	2.0	0.4	0.3	8.2
COV	0.0	0.1	0.1	0.1	0.2	0.1	0.5	1.2	0.3	0.3	0.1

Table 7-2. Water use statistics from 2005 U.S. EPA Combined Retrofit Report. (Adapted from Mayer et al. 2005).

	East Bay			Tampa			Seattle			Combined		
Attribute or usage category	Pre-retro	Post-retro	Savings	Pre-retro	Post-retro	Savings	Pre-retro	Post-retro	Savings	Pre-retro	Post-retro	Savings
Avg. age of house (yrs)		44			35			55			46	
Avg. house size (sf)		2,054			1,627			1,879			1,868	
Avg. no. of residents		2.74			2.92			2.51			2.7	
Avg. no. bathrooms		1.75			1			1.75			1.5	
Toilet usage	16.8	8.0	8.8	14.5	6.9	7.5	18.1	7.3	10.8	16.6	7.5	9.1
Showerhead usage	10.6	9.6	1.0	12.1	8.8	3.3	8.8	8.0	0.8	10.4	8.8	1.6
Faucet usage	9.0	8.8	0.3	8.5	6.1	2.4	8.4	7.2	1.3	8.6	7.4	1.2
Clothes washer usage	12.2	8.0	4.2	12.1	7.0	5.2	13.6	8.6	5.0	12.7	7.9	4.8
Leaks	15.8	7.2	8.6	15.3	2.9	12.4	6.9	2.2	4.7	12.4	4.1	8.3
Dishwasher usage	0.8	0.8	0.0	0.5	0.5	0.0	1.3	1.3	0.0	0.9	0.9	0.0
Other usage	3.2	2.8	0.4	3.1	3.5	-0.4	3.1	2.4	0.7	3.2	2.8	0.4
Total Indoor usage	68.5	45.2	23.2	66.0	35.6	30.4	60.2	36.9	23.3	64.8	39.4	25.4

Table 7-3. Water usage for conventional household devices in the United States. (Adapted from Metcalf and Eddy, Inc. 1975).

Device	Wastewater flow (gpcd)
Bathtub faucet	8
Clothes washer	9
Kitchen sink faucet	7
Bathroom faucet	3
Shower head	12
Toilet	24
Total	63

Table 7-4. Indoor usage for non-conserving households. (Adapted from Brown and Caldwell 1984)

Item	Calculation basis	Water use (gpcd)
Toilets	5.5 gal/flush x 4.0 flush/capita-day	22
Showers	3.4 gal/min x 4.8 min/capita-day	16.3
Clothes washer	55 gal/load x 0.30 load/capita-day	16.5
Dishwasher	14 gal/load x 0.17 load/capita-day	2.4
Faucets	Estimated	9
Baths	50 gal/bath x 0.14 bath/capita-day	7
Toilet leakage	0.17 x 24 gal/capita-day	4.1
Total		77.3

Table 7-5. 1984 indoor usage for intermediate households in the United States. (Adapted from Brown and Caldwell 1984).

Item	Calculation basis	Water use (gpcd)
Toilets w/ bottles,bags,dams	4.8 gal/flush x 4.0 flush/capita-day	19.2
Showers w/ flow restrictors	2.1 gal/min x 6 min/capita-day	12.6
Clothes washer	47.5 gal/load x 0.30 load/capita-day	14.3
Dishwasher	10 gal/load x 0.17 load/capita-day	1.7
Faucets	Estimated	9
Baths	50 gal/bath x 0.14 bath/capita-day	7
Toilet leakage	0.19 x 24 gal/capita-day	4.6
Total		68.4

Table 7-6. 1984 indoor usage for conserving households in the United States. (Adapted from Brown and Caldwell 1984).

Item	Calculation basis	Water use (gpcd)
Low flush toilets	3.5 gal/flush x 4.0 flush/capita-day	14
Low flow showers	1.9 gal/min x 4.3 min/capita-day	8.2
Clothes washer	42 gal/load x 0.30 load/capita-day	12.6
Dishwasher	8.5 gal/load x 0.17 load/capita-day	1.4
Faucets with aerators	Estimated	8.5
Baths	50 gal/bath x 0.14 bath/capita-day	7
Toilet leakage	0.33 x 24 gal/capita-day	8
Total		59.7

Table 7-7. 1984 indoor usage for all households in the United States. (Adapted from Brown and Caldwell 1984).

Item	Water use (gpcd)
Toilets	20
Showers	11.9
Clothes washer	12.6
Dishwasher	1.4
Faucets	9
Baths	7
Toilet leakage	4.3
Total	66.2

Table 7-8. Comparison of fixture use frequency for Brown and Caldwell (1984) and Mayer et al. (1999) studies. (Adapted from Brown and Caldwell 1984 and Mayer et al. 1999).

Frequency attribute	Brown and Caldwell (1984)	Mayer et al. (1999)
Toilet flush/capita-day	4	5.1
Number of showers/capita-day	0.74	0.7
Shower duration (min/capita-day)	4.3 - 6	8
Clothes washer loads/capita-day	0.3	0.37
Dishwasher loads/capita-day	0.17	0.1

Table 7-9. Estimated water use by household toilets. (Adapted from Mayer et al. 1999 and Aquacraft Inc. (2005).

Year manufactured or installed	Gallons per flush	Flushes per person per day	Toilet usage (gpcd)
1995- 2008	1.6	5.1	8.2
1980-1994	3.5	5.1	17.9
Pre 1980	5.0	5.1	25.5

Table 7-10. Estimated savings from toilet retrofits (gpcd)

	To		
From	5.0 gpf	3.5 gpf	1.6 gpf
5.0 gpf	0	7.6	17.3
3.5 gpf	-	0	9.7
1.6 gpf	-	-	0

Table 7-11. Estimated water use by showerheads (Adapted from Mayer et al. 1999 and Aquacraft Inc. (2005).

Year manufactured or installed	Gallons per minute	Showers per person per day	Shower duration (min)	Shower usage (gpcd)
1995- 2008	1.7	0.7	8	9.5
1980-1994	2.0	0.7	8	11.2
Pre 1980	4.3	0.7	8	24.1

Table 7-12. Estimated savings from showerhead retrofits (gpcd)

	To		
From	4.3 gpm	2 gpm	1.7 gpm
4.3 gpm	0	12.9	14.6
2 gpm	-	0	1.7
1.7 gpm	-	-	0

Table 7-13. Estimated water use by faucets. (Adapted from Mayer et al. 1999 and Aquacraft Inc. 2005).

Year manufactured or installed	Gallons per minute	Faucet use per person (minutes per day)	Faucet usage (gpcd)
1995- 2008	1.0	8.1	8.1
1980-1994	1.8	8.1	14.9
Pre 1980	3.3	8.1	27

Table 7-14. Estimated savings from faucet retrofits (gpcd)

	To		
From	3.3 gpm	1.8 gpm	1.0 gpm
3.3 gpm	0	12.1	18.9
1.8 gpm	-	0	6.8
1.0 gpm	-	-	0

Table 7-15. Estimated water use by clothes washers. (Adapted from Mayer et al. 1999 Aquacraft Inc. 2005).

Year manufactured or installed	Gallons per load (gpl)	Loads per person per day	Clothes washer usage (gpcd)
1995- 2008	27	0.37	10
1980-1994	51	0.37	14.4
Pre 1980	56	0.37	18.9

Table 7-16. Estimated savings from clothes washer retrofits (gpcd)

	To		
From	56 gpl	51 gpl	27 gpl
56 gpl	0	4.5	8.9
51 gpl	-	0	4.4
27 gpl	-	-	0

Table 7-17. Estimated leakage rates in SFRs. (Adapted from Mayer et al. 1999 and Aquacraft Inc. 2005).

Year manufactured or installed	Leakage rate (gpcd)
1995- 2008	9.5
1980-1994	11
Pre 1980	12.4

Table 7-18. Estimated water use by dishwashers. (Adapted from Mayer et al. 1999 and Aquacraft Inc. 2005).

Year manufactured or installed	Gallons per load (gpl)	Loads per person per day	Dish washer usage (gpcd)
1995-2008	4.5	0.1	0.5
1980-1994	14	0.1	1.4
Pre 1980	n/a	n/a	n/a

Table 7-19. Estimated savings from dishwasher retrofits (gpcd)

	To			
From	14 gpl	10.8 gpl	8.8 gpl	4.5 gpl
14 gpl	0	0.3	0.5	0.9
10.8 gpl	-	0	0.2	0.6
8.8 gpl	-	-	0	0.4
4.5 gpl	-	-	-	0

Table 7-20. Water fixture stock lookup table

Bathrooms	Toilets	Faucets	Showerheads
1	1	2	1
1.5	2	3	1
2	2	3	2
2.5	3	4	2
3	3	4	3
3.5	4	5	3
4	4	5	4
4.5	5	6	4
5	5	6	5
5.5	6	7	5
6	6	7	6
6.5	7	8	6
7	7	8	7
7.5	8	9	7

Table 7-21. Percentage of all GRU homes with given number of bathrooms from 1960- 2007

Number of Bathrooms	% of all homes
1	9.45%
1.5	3.37%
2	64.70%
2.5	8.20%
3	9.26%
3.5	2.57%
4	1.54%
4.5	0.54%
5	0.23%
5.5	0.07%
6	0.04%
6.5	0.01%
7	0.01%
7.5	0.01%
Total	100%

Table 7-22. Percentage of homes with clothes washers and dishwashers from Tampa-St. Petersburg American Housing Survey. (Adapted from U.S. Census Bureau 1987, U.S. Census Bureau 1991, U.S. Census Bureau 1995, U.S. Census Bureau 2000 U.S. Census Bureau 2009).

Year	% of homes with clothes washer	% of homes with dishwasher
2007	95	75
1998	89	66
1993	92	62
1989	90	57
1985	86	51

Table 7-23. Breakdown of all GRU accounts by year house built

Year house built	Count	%
Pre 1980	12,848	42%
1980-1994	10,200	33%
1995-2007	7,858	25%
Total	30,906	100%

Table 7-24. Difference between measured and calculated indoor end use gpcd assuming no base replacement

Fixture	Measured gpcd*	Calculated gpcd #	Difference
Toilet	18.5	18.6	0.1
Faucet	10.9	18.1	7.2
Showerhead	11.6	16.2	4.6
Clothes washer	15.0	15.2	0.2

* Measured end use values from Mayer et al. (1999)
# Calculated end use values for GRU assuming no natural replacement

Table 7-25. Predicted efficiency distribution of various fixtures for all GRU accounts

Fixture	% with low efficiency fixture	% with medium efficiency fixture	% with high efficiency fixture
Toilet	41%	33%	26%
Faucet	11%	12%	77%
Showerhead	11%	27%	62%
Clothes washer	41%	32%	28%

Table 7-26. Base replacement rates of fixtures for all GRU accounts

Fixture	Average annual base replacement rate of low efficiency fixtures	Average annual base replacement rate of medium efficiency fixtures
Toilet	0.05%	0.09%
Faucet	2.74%	5.39%
Showerhead	2.72%	1.50%
Clothes washer	0.12%	0.37%

Table 7-27. Summary of single family residential indoor usage coefficient recommendations

Coefficient	Recommendation
Number of accounts (n)	Historical data from utility. Time series analysis based on FDOR house year built data coupled with utility service area boundaries.
Indoor gpcd (x)	A default value of 70 gpcd for all SFRs may be used if a single point estimate is needed. Homes which retrofit old fixtures could reduce their indoor usage to as low as 40 gpcd.
People per house (α)	Use lognormal distribution of people per house in Florida. A default value of 2.5 people per house may be used if a single point estimate is needed.

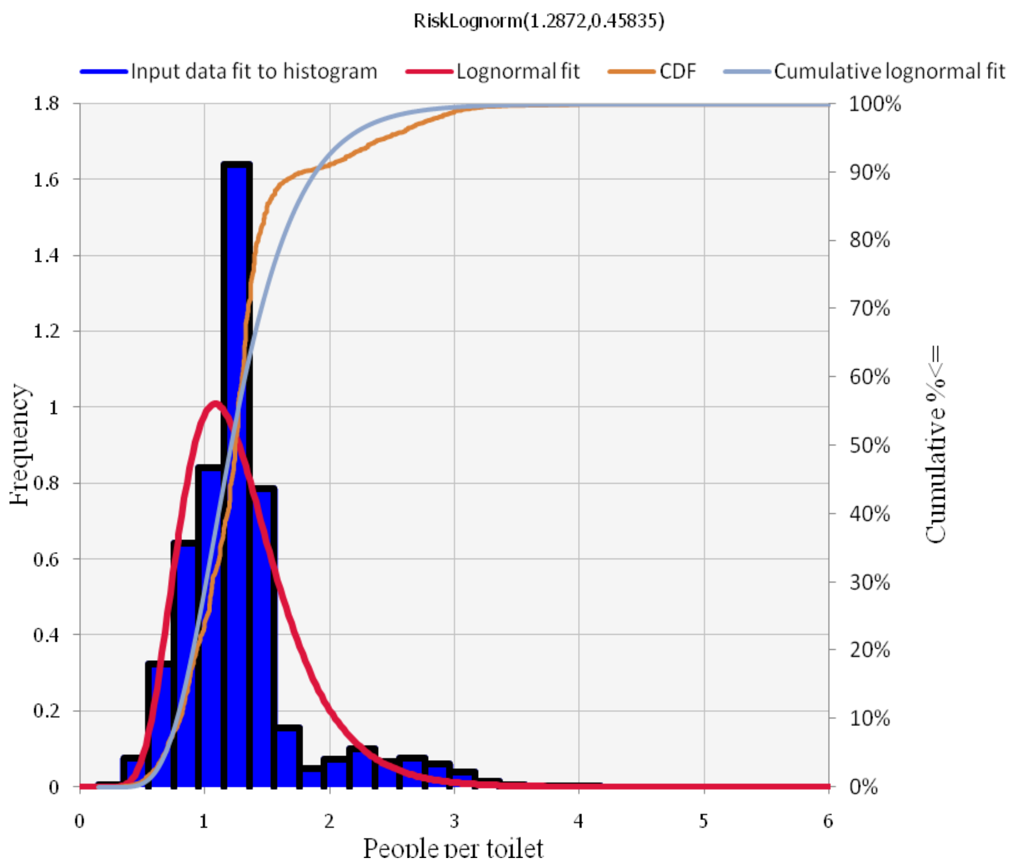


Figure 7-1. Pdf and cdf of people per toilet for all GRU

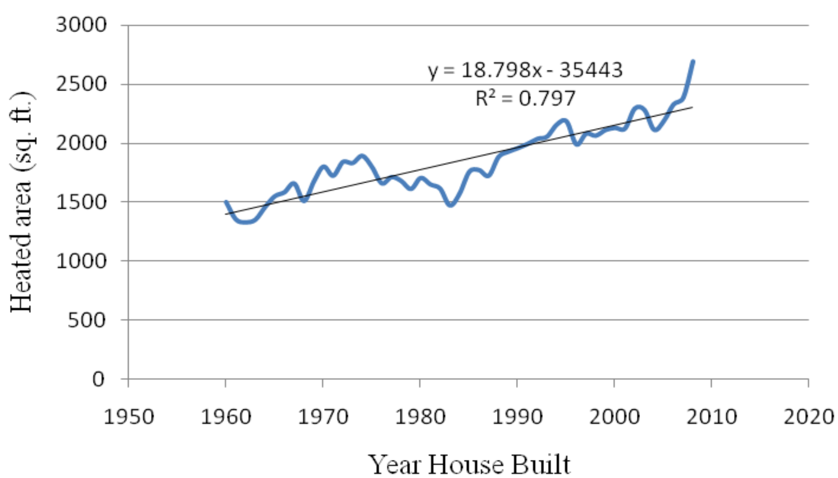


Figure 7-2. Heated area per house vs. year house built for all GRU

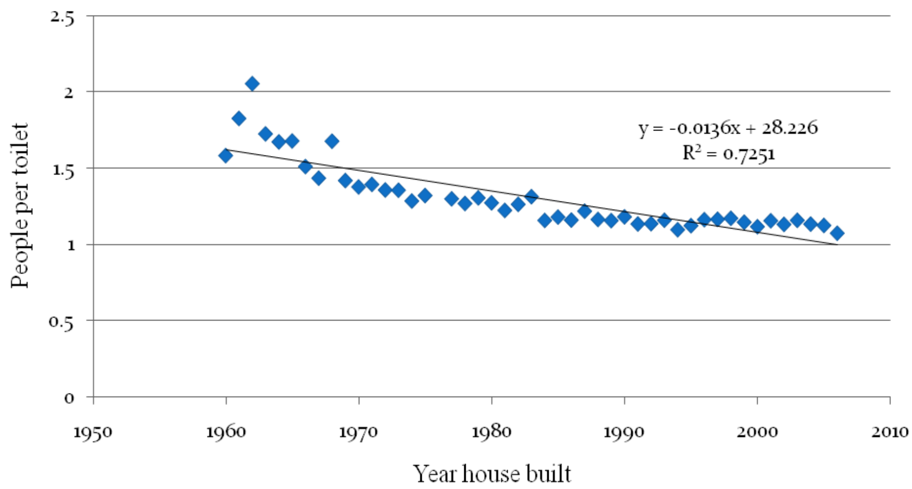


Figure 7-3. People per toilet vs. year house built for all GRU

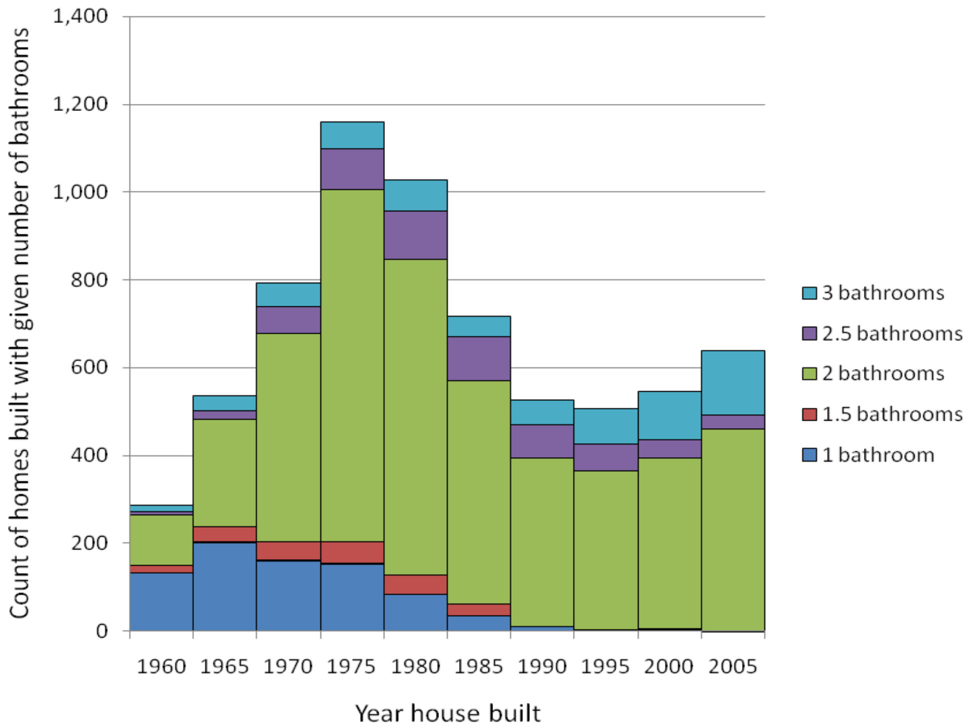


Figure 7-4. Count of single family residences built with given number of bathrooms in GRU for 1960-2005

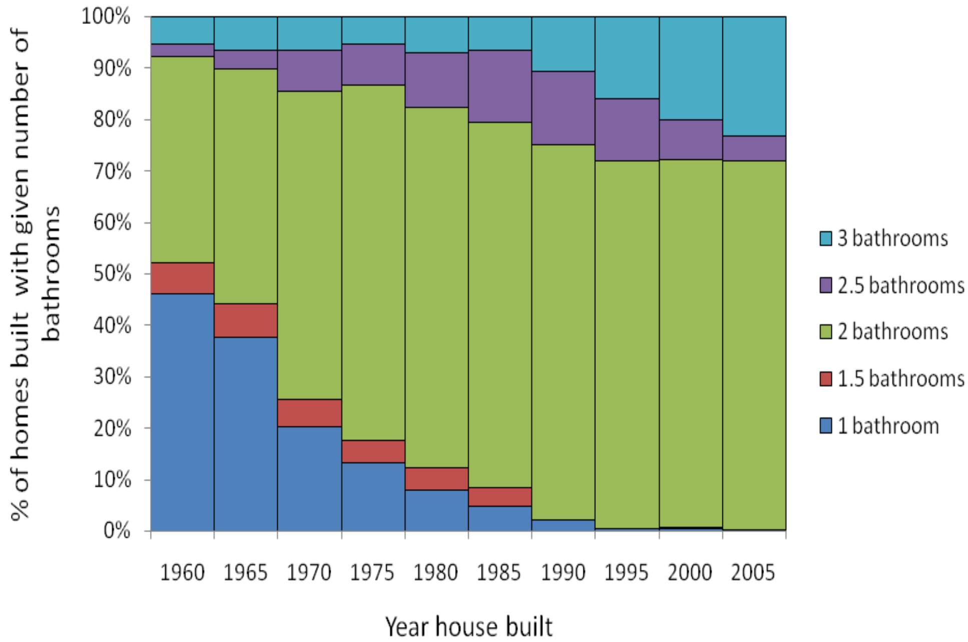


Figure 7-5. Percent of single family residences built with given number of bathrooms in GRU for 1960-2005

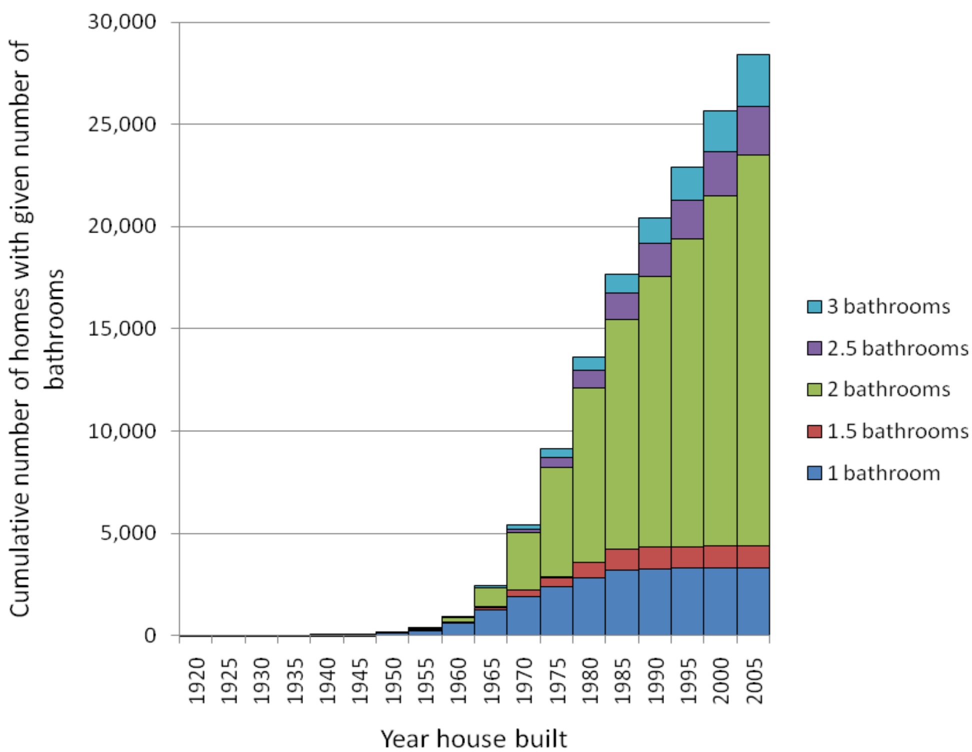


Figure 7-6. Cumulative number of single family residences built with given number of bathrooms in GRU for 1920-2005

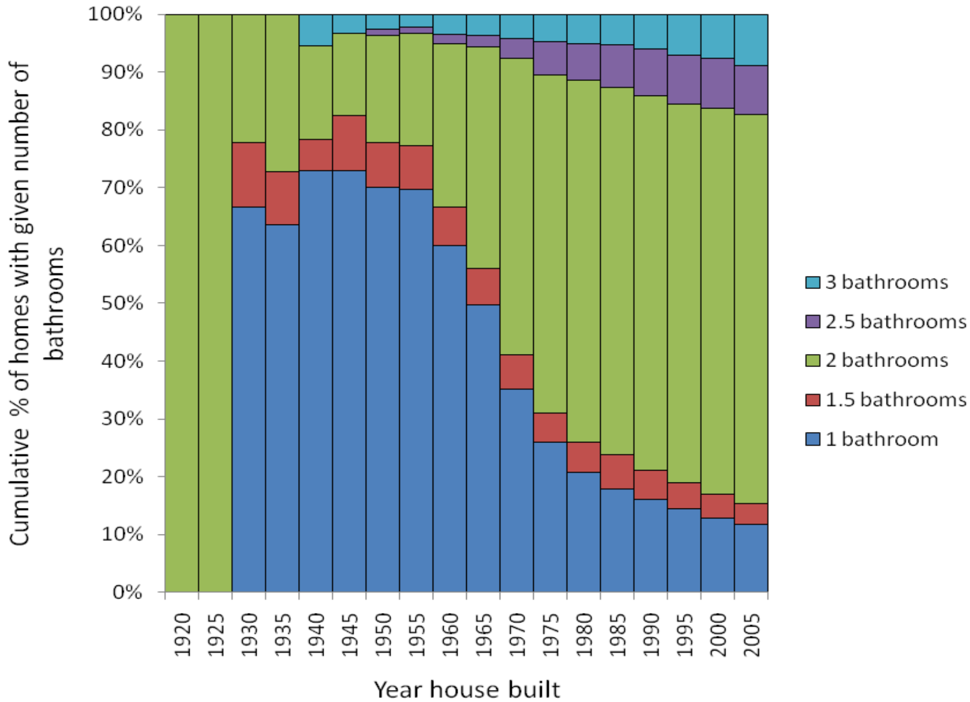


Figure 7-7. Cumulative percent of single family residences built with given number of bathrooms in GRU for 1920-2005

CHAPTER 8
POOL USAGE

Pool usage is part of indoor water usage due to the requirement for potable water to be used in pools. Pool usage can be calculated to analyze its conservation potential, and to more accurately determine outdoor usage using Equation 4-2.

Direct data on water usage for pools is not available for most utilities. Therefore, a process orientated approach must be used to approximate use of water for pools. Monthly pool water use, q, for the single family residential sector can be estimated using Equation 8-1. The number of people per house is the same as from the indoor usage analysis. The number of accounts with pools, as well as pool gallons per capita per day (gpcd) will be analyzed in this chapter.

$$q = 30.4 * \alpha * x * n \tag{8-1}$$

Where:

q = total single family residential (SFR) pool usage (gal/mo)
α = average number of people per SFR
x = average SFR pool usage rate coefficient (gpcd)
n = total number of SFR accounts with pools in the utility
30.4 = conversion factor from gal/day to gal/month

Trends in Number of Single Family Reidential Accounts with Pools

The trends in number of single family residential (SFR) accounts with pools in Florida were analyzed using the Gainesville Regional Utilities (GRU) customers as well as the Whitcomb (2005) customer datasets. For all 30,906 GRU customers in this study, the Alachua county Property Appraiser (ACPA) provided a field indicating whether customers had a pool. Such information is not normally available. About 7,000 SFR customers in the Whitcomb (2005) dataset were surveyed to determine whether they had a pool, with 3,514 responding. The Florida Department of Revenue (FDOR) database does not include pools as a parcel attribute. County property appraiser data varies from county to county in Florida, and no statewide database exists to directly determine number of accounts with pools in a utility. Therefore, trends analyzed using the GRU and Whitcomb 2005 datasets can be used as default values for a conservation plan addressing pool usage. A utility may replicate this analysis, depending on whether a link to property appraiser data can be made and their county property appraiser includes pools in its database.

All GRU SFR customer accounts were divided into four clusters: single meter with or without a pool, and dual meter with or without pool. Similarly, the 3,514 Whitcomb 2005 customers who responded can be grouped in terms of pool and non- pool customers. Attributes of these six clusters are summarized in Table 8-1. Overall, 6,163 out of 34,420 GRU SFR customers or 18% have pools. About 42% of the GRU dual metered SFR houses have pools. Similarly, 39% of the 3,514 Whitcomb SFRs have pools. Only 14% of the single meter GRU SFR customers have pools.

The dual metered GRU customers had much larger, more expensive, SFRs than the GRU single metered SFRs. The persons per house are relatively constant across these six categories. The presence of a pool is positively correlated with the interrelated size of house and house value attributes. A direct relationship between house value and pool ownership was also demonstrated in Whitcomb (2005) customers.

The yearly percent of all GRU and Whitcomb (2005) SFRs with pools from 1950-2007 is shown in Figure 8-1. The percentage of new homes built per year with pools increased linearly from 5% in 1950 to about 25% in 1994. Pools decreased in popularity from 1994 to 2007, with the percentage of new homes built per year with pools decreasing during this period from 25% to 13%. Linear regression techniques were used to quantify the linear relationships that are shown in Figure 8-2.

As shown in Table 8-1, the cumulative percent of GRU SFRs built with pools in 2007 is about 18%. Based on Figure 8-2, our best estimate is that about 10% of new, single meter houses built during the next 20 years will have pools.

Pool Gallons Per Capita Day

The dual meter SFR accounts with pools in GRU were used to analyze pool gpcd. No direct SFR pool usage data existed in any of the datasets used in this thesis. Therefore, a default estimate was made for Florida. Lee and Heaney (2008) have developed a pool usage model that estimates water usage over several years using a daily time step. Lee and Heaney (2008) estimate pool usage over time using a mass balance around a typical SFR pool, taking local precipitation, evaporation, and pool operating policies into account. They concluded that pools added about 5 gpcd to indoor water use.

Another approach to estimate pool usage analyzed the GRU dual metered accounts. Since all SFR customers in GRU could be assigned an indoor usage using methods shown previously, pool usage could be determined for dual metered customers with pools by subtracting estimated indoor gpcd from regular billed usage. These results are summarized in Table 8-2. The 584 GRU dual metered SFR accounts with pools have an estimated pool usage of 8 gpcd.

The dual metered customers with pools were compared with the GRU dual metered accounts without pools to analyze whether the 8 gpcd pool estimate was from a representative sample. As shown in Table 8-1, the GRU dual metered SFR accounts with a pool were not representative of typical customers. Random stratified sampling was performed for the dual metered accounts without pools such that the number of accounts and average heated area was about the same for these accounts without pools as for the GRU dual-metered SFR accounts with a pool. The dual metered SFR accounts without a pool were divided into three groups based on heated area. Random accounts from each of these groups were selected such that the number of

SFR accounts and average heated area of accounts without a pool was comparable to that of the GRU dual metered SFR accounts with a pool.

Next, the indoor gpcd for each sample was determined based on the recommendations from Chapter 7. The average, metered indoor gpcd for the dual metered SFR accounts without pools was also determined. The comparison of these two groups is summarized in Table 8-2. For the dual metered SFR accounts without pools, no sample of 584 customers could yield an average heated area similar to that of the dual metered SFR accounts with pools. The 308 largest SFRs in GRU were selected to achieve a sample with an average heated area similar to that of the dual metered SFR accounts with a pool.

The 2007 indoor gpcd estimates of the three samples were close to that of the dual metered SFR accounts with a pool. Interestingly, the difference between the metered and estimated indoor gpcd for the dual metered SFR accounts without a pool sample was only 1 gpcd. This finding suggests that the methods used to determine indoor gpcd from Chapter 7 were accurate. Based on the comparison of the three sample clusters to that of the dual metered GRU SFR accounts with pools, an average pool usage of 8 gpcd provides an upper bound on pool usage.

The value of 8 gpcd is slightly higher than other pool models, which have suggested that pool usage is around 5 gpcd (Lee and Heaney 2008). It is possible that GRU’s dual metered customers use slightly more pool water since these SFRs are atypical houses. These homes may use more water due to family income or due to a pool size that is larger than most homes with pools. For these reasons, a default pool usage value of 5 gpcd is recommended for Florida with an upper bound of 8 gpcd.

Final Pool Usage Recommendations

The final pool usage recommendations are summarized in Table 8-3. Pool usage can be estimated for a utility in Florida according to Equation 8-1.

Table 8-1. Comparison of pool and non-pool SFR customers in Florida

Attribute	Dual metered w/pool GRU	Dual metered w/o pool GRU	Single meter w/ pool GRU	Single meter w/o pool GRU	Single meter w/pool Whitcomb	Single meter w/o pool Whitcomb	Total w/pool	Total w/o pool
Number of accounts	584	818	4,209	25,295	1,370	2,144	6,163	28,257
Avg. people per home	2.64	2.56	2.64	2.51	2.67	2.40	2.65	2.50
Avg. house year built	1993	1993	1985	1983	1975	1979	1984	1983
Avg. heated area (ft^2)	3,132	2,389	2,548	1,659	2,560	1,988	2,606	1,705
Avg. value ($)	427,077	287,699	299,378	171,807	167,697	103,853	282,207	170,006

Table 8-2. Comparison of SFR dual metered GRU customers with pools to SFR dual metered GRU customers without pools

Attribute	Dual metered w/pool GRU	Dual metered w/o pool GRU
Number of accounts	584	308
Avg. people per home	2.64	2.58
Avg. house year built	1993	1995
Avg. heated area (ft^2)	3,132	3,135
Avg. value ($)	427,077	394,039
2007 indoor gpcd estimate	68	67
10/07-9/08 metered indoor gpcd	76	68
Pool gpcd estimate	8	N/A

Table 8-3. Summary of single family residential pool usage coefficient recommendations

Coefficient	Recommendation
Number of accounts with pools (n)	Percentage of accounts built with pools varies based on year house built. Pre 1950-:assume no pools built 1950-1994: y=0.0046x – 8.9271 1995-2007: y=-0.0094x +18.92 2008-2028: assume 10% of homes have pools Add years together to determine total accounts with pools
Pool gpcd (x)	A constant value of 5 gpcd can be used as a default value with an upper bound of 8 gpcd
People per house (α)	Same as for indoor usage

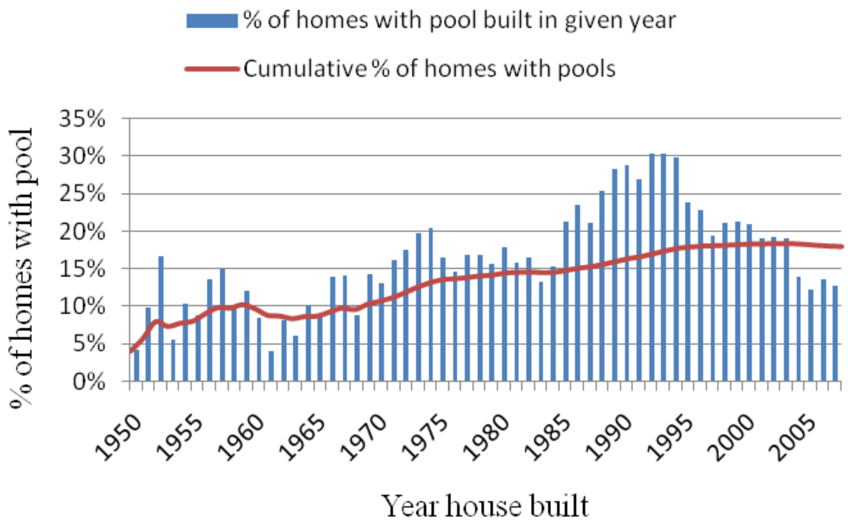


Figure 8-1. Trends in SFRs built with pools in Florida for all GRU and Whitcomb (2005) customers

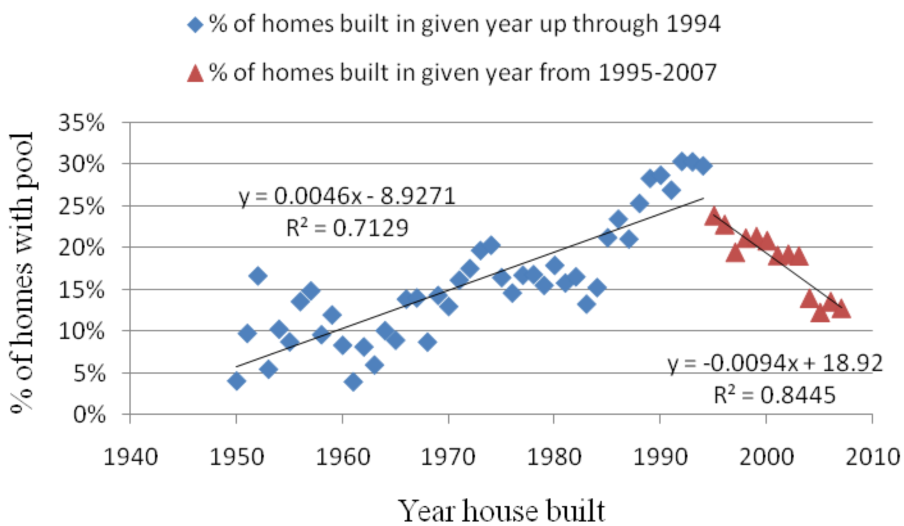


Figure 8-2. Linear regression of percent of SFRs with pool vs. year house built for all GRU and Whitcomb (2005) SFR customers

CHAPTER 9
SUMMARY, CONCLUSIONS AND FUTURE WORK

A water conservation plan can be defined quantitatively by performing a water budget followed by Best Management Practice (BMP) planning and finally implementing conservation initiatives and tracking performance. Water use is broken down into multiple sectors to determine where conservation should be targeted. This thesis focuses on water loss and indoor water usage in single-family residences for the purpose of identifying water-conservation options in Florida

Water loss has been typically analyzed using water audits. The 2009 Version 4.0 American Water works Association (AWWA) water audit, coupled with the 2009 third edition of the AWWA M36 manual, provide a solid framework that can be incorporated into the water budget portion of a conservation plan. However, it is recommended that water loss be expressed as gallons per capita per day (gpcd) to compare with other sectors of water use. Water loss can be incorporated as a BMP in Florida using similar methods to those in California, with a recommended initial data collection phase. A default value of 15% water loss can be used as an upper bound for utilities that cannot complete and validate water loss calculations.

Traditional methods of estimating indoor water usage, using the minimum month method, may not work for Florida due to year round irrigation. Indoor usage in single family residences was shown to be a function of the number of accounts in a utility, the number of people per house, and the individual per person indoor water usage rate (gpcd). Default coefficients, in conjunction with widely available data for utilities were used to estimate the parameters of indoor water usage. The projected number of SFR accounts in a utility depends on land availability, and can be determined through time series analysis. The number of people per house in Florida was around 2.5, and a lognormal distribution was developed to approximate people per house in Florida. Indoor water usage was shown to have little seasonal variability. Indoor gpcd was shown to be declining in recent years due to improved fixture efficiency. Toilets were the largest component of indoor water usage and had the largest potential impact in reducing indoor water usage. Thus, a promising BMP plan is to retrofit less efficient but higher use toilets in older homes which have fewer toilets per person.

Pool usage is considered a part of indoor water usage due to the requirement for potable water in pools. Pool usage can be calculated to analyze its conservation potential, and to more accurately determine outdoor usage Pool usage data was not directly available for Florida utilities. Therefore, default coefficients were recommended to estimate pool usage. The percent of homes built with pools varied based on year house built. Homes with pools increased from 1960 through 1994 and decreased from 1994-2007. It was assumed that 10% of new homes in years after 2007 would have pools. Pool gpcd was estimated at 5 gpcd with an upper bound of 8 gpcd, based on GRU dual metered billing data and pool simulation models. Pool usage was shown to be a small component of total water usage. A summary of the recommended indoor water usage coefficients, including pool usage is shown in Table 9-1.

Although this thesis recommends several procedures for analyzing water loss and single family indoor water usage for the purpose of developing a water- conservation option, these recommendations have not yet been implemented or tested in the field. The next step in this analysis is to create an implementation schedule to correct meter error, retrofit toilets, etc. Once implemented, actual water savings can be measured to see if the plan has worked. Then, these results can be used to create future conservation plans.

Conclusions from this thesis will be part of the Conserve Florida Water EZ Guide. With the methods described in this thesis, utilities in Florida can develop cost-effective conservation plans for sustainable future water systems that balance supply and demand management.

Table 9-1. Summary of single family residential indoor usage coefficient recommendations, including pool usage coefficient recommendations

Coefficient	Recommendation
Number of accounts (n)	Historical data from utility. Time series analysis based on FDOR house year built data coupled with utility boundaries.
Indoor gpcd (x)	A default value of 70 gpcd for all SFRs may be used if a single point estimate is needed. Homes which retrofit old fixtures could reduce their indoor usage to as low as 40 gpcd.
People per house (α)	Use lognormal distribution of people per house in Florida. A default value of 2.5 people per house may be used if a single point estimate is needed.
Number of accounts with pools (n)	Percentage of accounts built with pools varies based on year house built. Pre 1950-:assume no pools built 1950-1994: $y=0.0046x - 8.9271$ 1995-2007: $y=-0.0094x +18.92$ 2008-2028: assume 10% of homes have pools Add years together to determine total accounts with pools.
Pool gpcd (x)	A constant value of 5 gpcd can be used as a default value with an upper bound of 8 gpcd.

APPENDIX A
ILLUSTRATION OF DETERMINING LOGNORMAL PEOPLE PER HOUSE DISTRIBUTION

The lognormal probability distribution of people per house can be determined based of the mean people per household (pph) value obtained from U.S. Census data and a 0.5 coefficient of variation to determine the standard deviation. The mean pph value can be either obtained from the U.S. Census Web site, or by using the census block method described in Chapter 5. Maidment (1993) and Singh et al. (2007) present the generalized methodology of determining lognormal distributions from observed sample values for mean and variance. This methodology was applied for determination of the lognormal people per house distribution.

Let X be a random variable for the average people per house in a utility service area. Assuming that X follows a lognormal distribution, then the cumulative density function (cdf) for X can be determined as shown in Equation A-1.

$$F_x(x, \mu, \sigma) = P(X \le x) = \frac{1}{x\sigma_y\sqrt{2\pi}}\exp\left(-\frac{(\ln(x)-\mu_y)^2}{2\sigma_y{}^2}\right), x > 0 \qquad \text{(A-1)}$$

Where:

F_x = the cdf for X
x = average people per house values, greater than 0
μ_y = the mean of $\ln(x_i)$
σ_y= the standard deviation of $\ln(x_i)$

The expected value and standard deviation of X can be obtained using Equations A-2 and A-3 respectively.

$$E[X] = \exp(\mu_y + \frac{1}{2}\sigma_y{}^2) \qquad \text{(A-2)}$$

$$Var[X] = (St.Dev.[X])^2 = (\exp(\sigma_y{}^2) - 1)\cdot\exp(2\mu_y + \sigma_y{}^2) \qquad \text{(A-3)}$$

It should be noted that μ and σ in Equation A-1 are the mean and standard deviation of the log transform of X. Therefore, the mean pph obtained from U.S. census data cannot be directly used in Equation A-1. However, since X is assumed to be log normally distributed, the mean pph obtained from census data can be used to approximate E[X]. The standard deviation of X can be determined assuming a coefficient of variation (COV) of 0.5 according to Equation A-4 and can be used to approximate St. Dev. [X].

$$\sigma_x = COV \cdot \mu_x \tag{A-4}$$

Where:

μ_x = the mean of the sample people per house values, x_i
σ_x= the standard deviation of the sample people per house values, x_i
COV = coefficient of variation, 0.5

Equations A-2 and A-3 can be rearranged to solve for μ and σ in terms of E[X] and Var[X] as shown in Equations A-5 and A-6.

$$\mu_y = \ln(E[X]) - \frac{1}{2}\ln(1 + \frac{Var[X]}{E[X]^2}) \tag{A-5}$$

$$\sigma_y = \sqrt{\ln(1 + \frac{Var[X]}{E[X]^2}} \tag{A-6}$$

Since E[X] ~ μ_x and Var[X] ~ $\sigma^2_{x,}$ equations A-5 and A-6 can be re-written such that the log normal distribution parameters μ and σ can be directly calculated from μ_x and σ_x ,which are directly determined from U.S. Census data. This is shown as Equations A-7 and A-8, which are the equations to be used in the EZGuide to determine a utility's lognormal people per house distribution from U.S. Census data.

$$\mu_y = \ln(\mu_x) - \frac{1}{2}\ln(1 + \frac{\sigma_x{}^2}{\mu_x{}^2}) \tag{A-7}$$

$$\sigma_y = \sqrt{\ln(1 + \frac{\sigma_x^{\ 2}}{\mu_x^{\ 2}})} \qquad \text{(A-8)}$$

APPENDIX B
CALIBRATION OF BASE REPLACEMENT MODELS

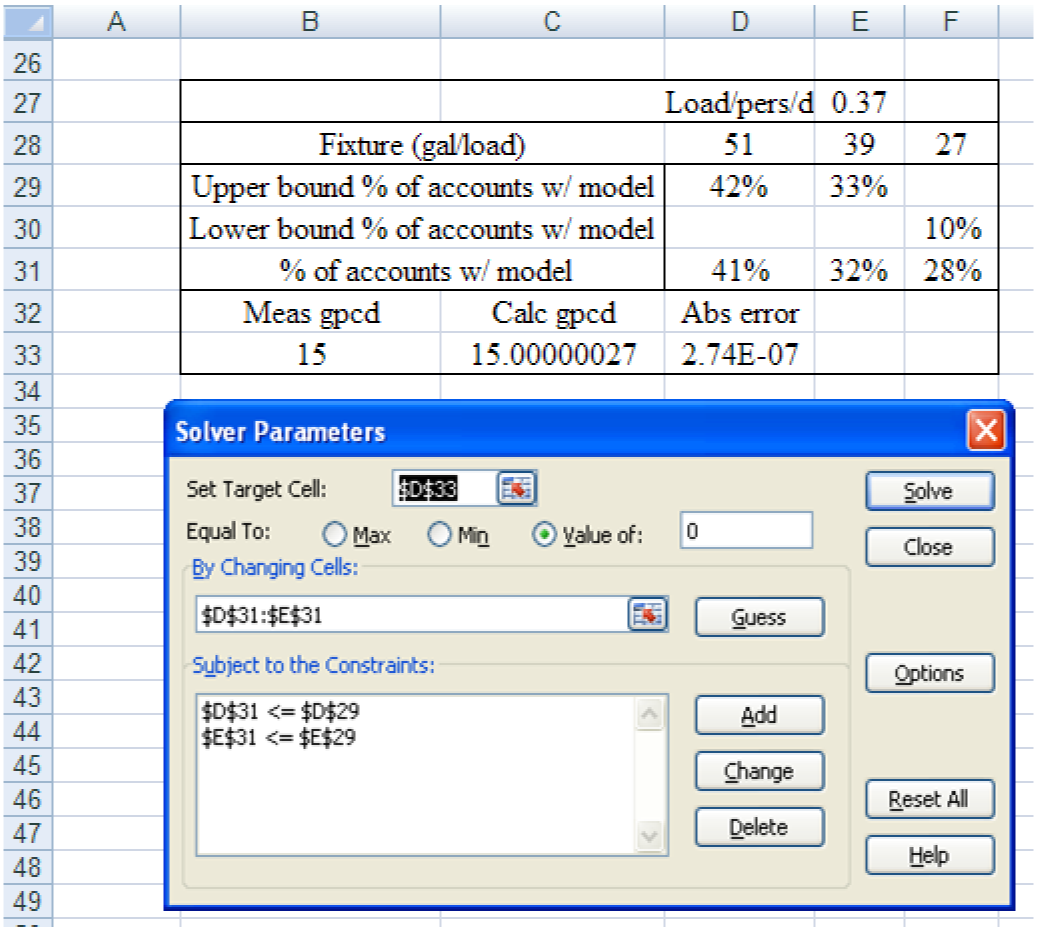


Figure B-1. Clothes washer base replacement model for GRU

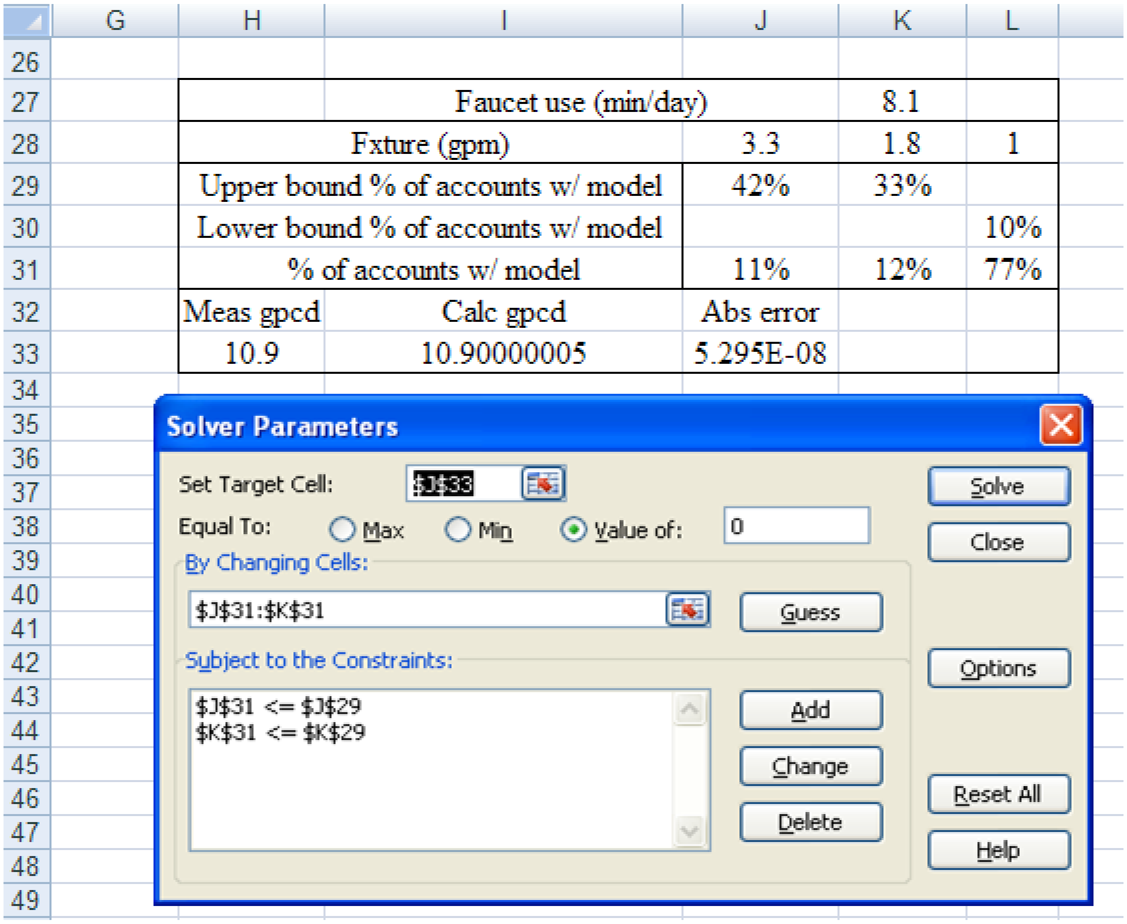
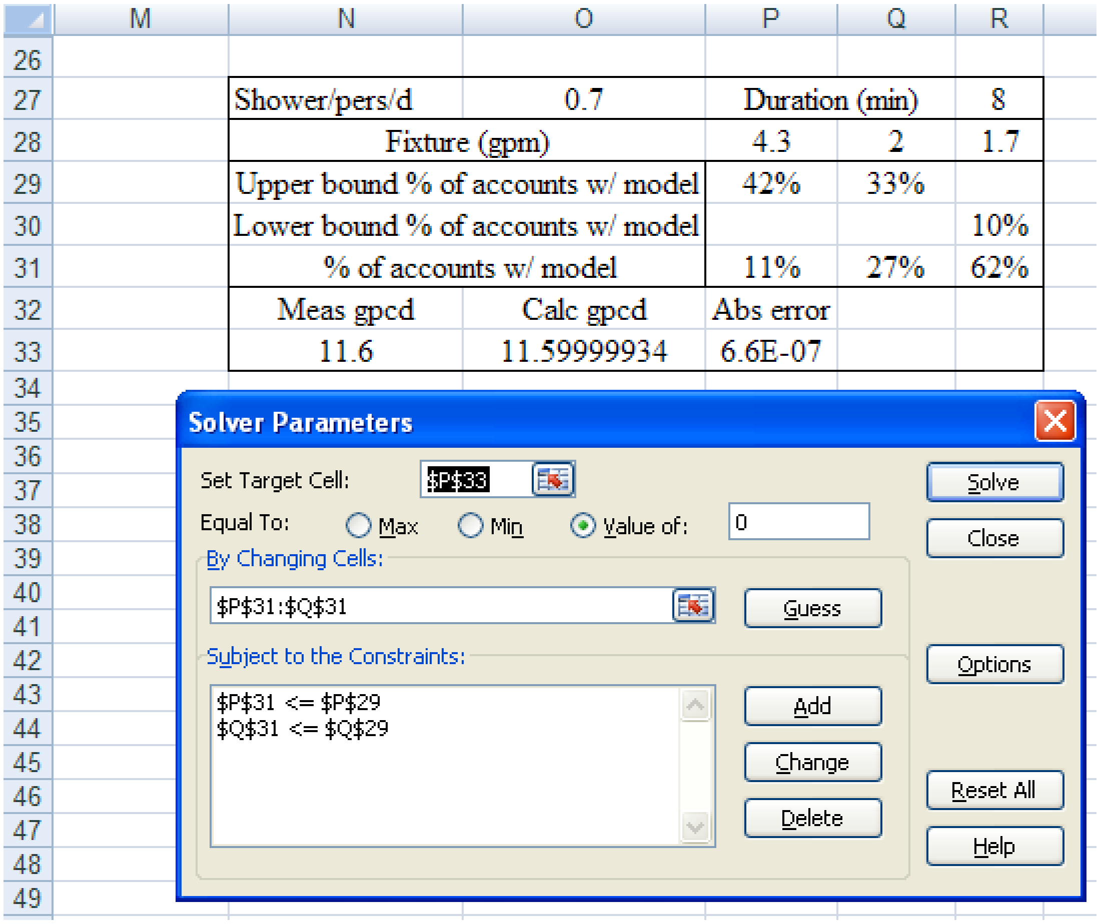


Figure B-2. Faucet base replacement model for GRU



Shower/pers/d	0.7	Duration (min)		8
Fixture (gpm)		4.3	2	1.7
Upper bound % of accounts w/ model		42%	33%	
Lower bound % of accounts w/ model				10%
% of accounts w/ model		11%	27%	62%
Meas gpcd	Calc gpcd	Abs error		
11.6	11.59999934	6.6E-07		

Figure B-3. Showerhead base replacement model for GRU

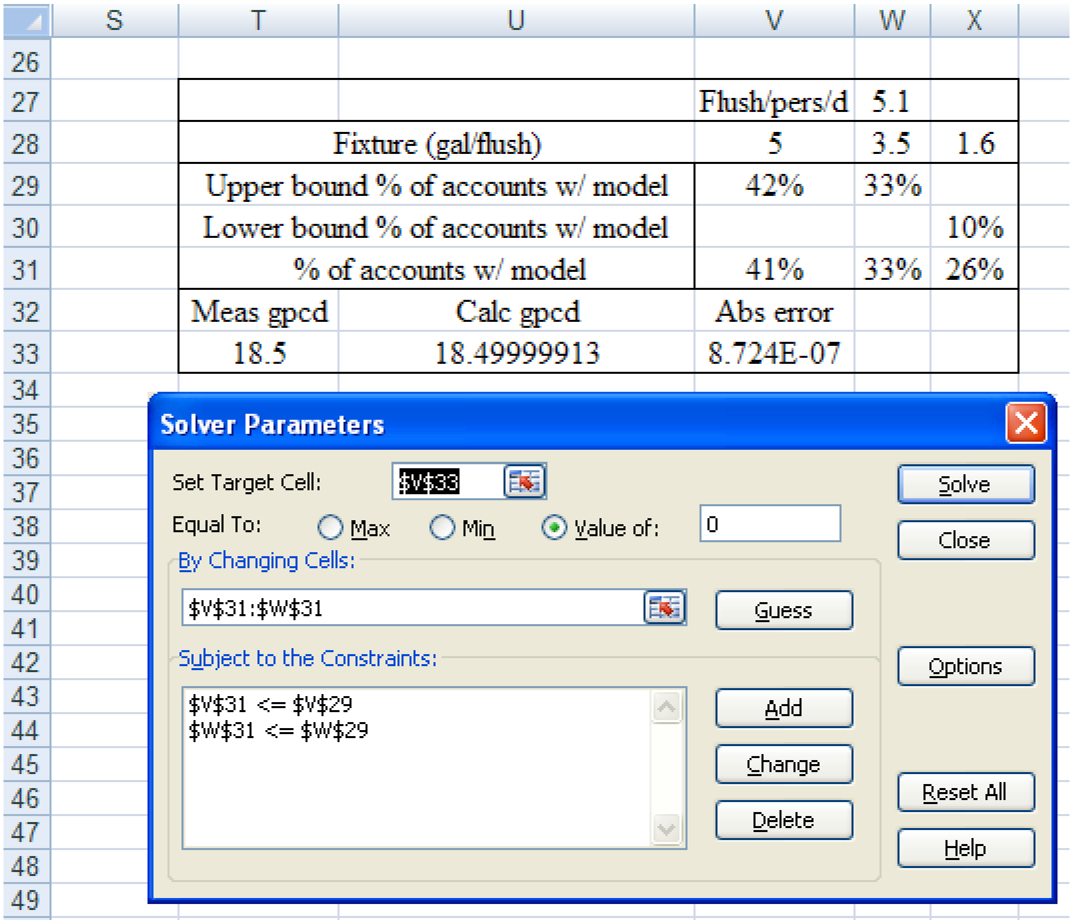


Figure B-4. Toilet base replacement model for GRU

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BIOGRAPHICAL SKETCH

Kenneth Friedman was born in Highland Park, IL in 1984. He is an only child and moved to Coral Springs, Fl at age 6. While attending high school in Coral Springs, he developed his passion for problem solving and environmental studies.

Ken decided to major in environmental engineering at the University of Florida since it combined his two main academic passions. He started his undergraduate work in 2003 and received his undergraduate environmental engineering degree in 2007.

Starting in August 2007, Ken began his work as a graduate student studying water conservation under Dr. Heaney. He began working with customer billing databases and summarizing water usage by sectors. Later, Ken studied the areas of system water loss and residential end use analysis. These areas of study led to GIS analysis and Excel modeling, both of which were very rewarding and exciting analysis tools. Ken received his M.E. from the University of Florida in the fall of 2009 and will continue his work in the water resources and water conservation planning fields.