Water Use and Demand Management Options for the Multi-family Residential Sector

Kenneth R. Friedman, James P. Heaney, Miguel A. Morales, and Randy Switt
Department of Environmental Engineering
University of Florida
Gainesville, FL
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Kenneth R. Friedman and Miguel A. Morales are PhD students, Randy Switt is an Assistant in Engineering and James P. Heaney is a Professor in the Department of Environmental Engineering Sciences at the University of Florida.

INTRODUCTION

Public water use can be disaggregated into water demand sectors for evaluating water conservation options. Typical disaggregation partitions total public supply into commercial, industrial and residential sectors as well as unaccounted for water in the treatment and/or distribution system. Oftentimes, the residential sector is not further broken down into single and multi-family sectors, despite residential usage representing the largest percentage of public supply water usage in the U.S. and Florida. The USGS estimated water use from public supplies across the United States in 1995 as 56% domestic (residential), 17% commercial, 12% industrial, and 15% public use and losses (Solley et al. 1998). Water losses are usually dealt with separately from public use. Domestic (residential) usage in Florida during 2005 was 95 gpcd or 60% of the total 158 gpcd used for public supply (Marella 2008).

Multi-family users account for a significant portion of residential and total public water use in Florida. The U.S. Census (2010) reported an overall 2009 Florida population of over 18.5 million people and 8.85 total housing units. A total of 29.9% of these housing units are multi-family and some of these housing units are unoccupied. In addition to accounting for a significant portion of total public water usage in Florida, the multi-family sector should be analyzed independently from single family and other sectors since it represents a homogeneous sector with unique attributes. Analyzing homogeneous groups is necessary for accurate water demand and conservation analysis. Multi-family usage may differ from single family usage for several reasons including:

- land uses and parcel boundaries
- average household size
- occupancy rate
- irrigable area per unit

One major difference between the single and multi-family sectors is the way in which they are metered and billed. Single family homes are typically metered and billed individually whereas the multi-family sector typically meters and bills a single owner of a building (Mayer et al. 2005). Mayer et al. (2005) showed that individually metering homes decreases water usage as customers become more aware of their usage. Mayer et al. (2005) also recommended that incentives for replacing indoor water using devices (toilets, showerheads, etc.) in multi-family units built before 1995 should be implemented to reduce water usage. Residential plumbing retrofits are widely adopted as a best management practice for water conservation (Maddaus 2006). However, Mayer et al. (2005) point out that additional incentives to retrofit might need to be implemented in multi-family complexes with submeters as property owners will have less incentive to retrofit fixtures.

Several methods exist for determining a sectoral breakdown of total public supply. Dziegielewski and Opitz (2002) describe how sector disaggregation can be done given premise codes in billing data to distinguish sectors, although they recognize that this data is not always available. They also mention that meter sizes can be used to approximate sectoral breakdown although this method is not as accurate as billing premise codes.

The main limitations of current methods to analyze multi-family residences is that they either rely on simple aggregate estimates or require detailed customer billing data or site specific data. These methods also rely on default savings rates to evaluate conservation alternatives rather than directly calculating savings. These methods may not be accurate or applicable to most utilities in Florida. Given these limitations, a new methodology to estimate multi-family residential water usage and conservation options, based on parcel-level land use and water billing databases, is presented in this paper. The Florida Department of Revenue (FDOR) database provides attributes for every parcel in the State along with their land use classification. The FDOR database in conjunction with Florida County Property Appraisers (FCPA), U.S. Census, and customer billing data provided by Gainesville Regional Utilities (GRU) allows for a parcel-level evaluation of multi-family water usage and for direct evaluation of conservation best management practices (BMPs) which can be applied to any utility in Florida. This methodology to determine multi-family accounts, analyze their property attributes and water usage, and evaluate BMP alternatives is discussed in this paper.

WATER USE ESTIMATION METHODOLOGY

Monthly water use, q, in any sector can be estimated using Equation 1, as the product of an activity coefficient; a measure of the size of the activity, e.g., people per house; the occupancy rate for this activity; and the number of accounts in this category as shown in Equation 1.

$$q = 30.4 \cdot a \cdot x \cdot r \cdot n \qquad (1)$$

Where:
q = total water usage (gallons/month)
a = water usage rate coefficient (daily gallons per unit of size)
x = size of the activity, e.g., persons per residence
r = occupancy rate
n = number of customers in the group
30.4 = conversion factor from gallons/day to gallons/month

Equation 1can be generalized to determine water usage for any subgroup, m, of customers within the utility. The total usage would then be the summation of the subgroup totals, as shown by Equation 2.

$$q = 30.4 \cdot \sum_{i=1}^{m} (a_i \cdot x_i \cdot r_i \cdot n_i) \qquad (2)$$

The number of subgroups depends on the desired aggregation and the availability of data at various spatial scales. Customers can be divided into groups based on attributes such as house size, water using fixtures, family income, year house built, etc. Customers can also be disaggregated geographically, such as groups based on spatial units such as census blocks, traffic analysis zones, or utility boundaries. This approach also allows for complete disaggregation of customers. Methods for determining water usage for the multi-family sector will be discussed in detail in the next sections.

DEFINING THE MULTI-FAMILY SECTOR

As shown in Equations 1 and 2, public water use for a given utility can be presented as a single value over all uses or partitioned into usage by sectors as well as subgroups of sectors. Utilities vary widely on how sectors are identified ranging from only one sector to dividing water users by meter size or premise codes. The six major water use sectors generally used are:

- Single family residential
- Multi-family residential
- Commercial
- Industrial
- Institutional
- Unaccounted for water

The FDOR database provides a land use description for every parcel in Florida. The land use descriptions are categorized by 100 two digit use codes, defined by FDOR (2009). FDOR then groups the 100 two digit codes by property type. The 66 codes per property type relevant to public supply water usage are:

- Residential-9 land use types
- Commercial-28 land use types
- Industrial-11 land use types
- Institutional (and government)- 18 land use types

The other land use codes represent agricultural, miscellaneous, or vacant property, which is not relevant to public supply water usage analysis. FDOR does not specifically distinguish between single and multi-family land use codes. However, FDOR defines basic stratum for property classification, as defined by Florida Statute 195.096(3)(a) which includes an apparent distinction between single and multi-family land use codes. However, this classification may not be appropriate for delineating among use codes for water use analysis. For example, FDOR use code DORUC 28 largely represents mobile home parks, which is classified as a commercial property although this use code may exhibit characteristics of multi-family properties more so than commercial properties for the purposes of water usage analysis. Table 1 shows FDOR use codes which exhibit characteristics of a homogenous multi-family grouping and how they are currently aggregated by FDOR. Condominiums, mobile homes, and cooperatives are grouped with single family homes by FDOR.

Table 1. Potential FDOR use codes for multi-family water usage analysis

DORUC	FDOR stratum	FDOR description
1	Single family res.	Single Family Residential
2	Single family res.	Mobile Homes
3	Multi-family res.	Multi-family – 10 units or more
4	Single family res.	Condominiums
5	Single family res.	Cooperatives
6	Multi-family res.	Retirement Homes
7	Multi-family res.	Miscellaneous Residential
8	Multi-family res.	Multi-family – less than 10 units
28	Commercial	Mobile Home Parks

Multi-family residences are defined more explicitly by various other entities. For example, multi-family residences are defined to include condos and mobile homes in the Gainesville Regional Metropolitan Plan (Corradino Group, Inc. 2005). The 2007 Tampa American Housing Survey (AHS) delineates condominiums, mobile homes and cooperatives from multi-unit living structures in their housing statistics, but does not group these with single family homes (U.S. Census Bureau 2009). The U.S. Census excludes single family and mobile homes when defining housing units in multi-family structures, and categorizes multi-family units into groups based on number of units per structure in some cases (U.S. Census 2010). The utilization of FDOR stratum and FDOR land use codes to define the multi-family sector for water usage analysis will be analyzed in this paper.

STATEWIDE RESIDENTIAL LAND USE CODES

A statewide analysis of the nine residential land use codes determined the relative importance as well as comparative descriptive attributes of each land use code in Florida. The FDOR database for all parcels in the state of Florida that fall into nine residential DOR categories shown in Table 2 compares the relative size of each land use code. These categories reflect over 80% of the total 8.8 million parcels on Florida. Single family residential homes are the dominant residential land use category, constituting 68% of the total residential parcels and 70% of the total heated area. Cooperatives, retirement homes, miscellaneous residential, and mobile home parks represent very small use groups, each constituting one percent or less of total residential parcels and total heated area. Multi-family structures with 10 or more units accounted for less than 1 percent of total residential parcels but make up 6.6% of the heated area of all residential structures in Florida.

Table 2. Size attributes for potential FDOR use codes for multi-family water usage analysis

DORUC	FDOR stratum	FDOR description	Total parcels (thousands)	Percent of total parcels	Total heated area (million sf.)	Percent of total heated area	Heated area (sf)/parcel	Total res. units (thousands)	Units/ parcel	Heated area (sf)/unit
1	Single family res.	Single Family Residential	4,861	68%	8,885	70%	1,828	4,449	0.92	1,997
2	Single family res.	Mobile Homes	446	6%	509	4%	1,142	440	0.99	1,156
3	Multi-family res.	Multi-family – 10 units or more	14	0%	838	7%	59,587	746	53.04	1,123
4	Single family res.	Condominiums	1,569	22%	1,920	15%	1,224	1,547	0.99	1,241
5	Single family res.	Cooperatives	41	1%	39	0%	969	35	0.87	1,118
6	Multi-family res.	Retirement Homes	1	0%	45	0%	78,944	23	40.45	1,952
7	Multi-family res.	Miscellaneous residential	27	0%	9	0%	330	5	0.20	1,636
8	Multi-family res.	Multi-family – less than 10 units	162	2%	375	3%	2,321	304	1.88	1,234
28	Commercial	Mobile home parks	15	0%	151	1%	9,757	72	4.66	2,095
		Total	7,135	100%	12,773	100%	1,790	7,622	1.07	1,676

Mobile homes (DORUC 2) exhibit characteristics similar to single family residential homes (DORUC 1). Like single family homes, mobile homes are single residential unit structures on a parcel containing its irrigable area. Mobile homes should be grouped in the single family residential stratum for water usage analysis. The seven remaining use codes (3-8, 28) will be analyzed in more detail.

A case study utilizing FDOR data combined with detailed property appraiser data for Gainesville, FL in Alachua County was used to analyze the seven potential multi-family residential FDOR codes in greater detail. This was done to develop a statewide methodology for estimating multi-family water usage following the general formulation expressed in Equation 2. Potential conservation options were also analyzed utilizing this case study.

DATASETS USED TO EVALUATE MULTI-FAMILY WATER USAGE

Several datasets were used to analyze multi-family usage and to determine multi-family usage coefficients in Florida. Some of these datasets provide macro-scale data available for 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 usage coefficients could be determined using only widely available FDOR parcel data coupled with default values from more specific property appraiser and data sources, if necessary. If a utility chooses, the default values can be replaced by more accurate values using their more detailed data.

The FDOR parcel data was combined with Alachua County Property Appraiser, GRU customer billing, and U.S. Census block data to create the Gainesville, FL case study. This dataset combined with detailed site specific end use studies allowed for more accurate analysis of multi-family usage in Florida.

Florida Department of Revenue

FDOR maintains a property attribute database for 8.8 million parcels of land in the state of Florida. This database can be obtained by the public for free from the FDOR FTP website (ftp://sdrftp03.dor.state.fl.us/). This database is audited and updated annually. Until 2009, tabular attribute data stored in NAL (name address legal) files often was inconsistent with spatial data. Combining these two datasets is a labor intensive process. The Florida Geographic Library (FGDL) took on this challenge and currently has the 2009 FDOR tabular data combined with spatial attributes and a link to U.S. Census data available for free download by county.

(http://www.fgdl.org/metadataexplorer/explorer.jsp) (Search "FDOR parcel" and click download for "Florida Parcels by County-2009", and then select which county to download). The FGDL 2009 FDOR data was utilized for the analysis in this paper.

FDOR partitions parcels based on their land use into 100 sectors using two-digit FDOR codes, as explained above. These codes are standardized across the State, providing consistent definitions of terms. The parcel information in this database is provided annually by the State's 67 Florida County Property Appraisers (FCPAs) to FDOR for a statewide land-use database.

The following attributes of interest are provided by the FDOR database:

- parcel ID number
- land use code
- number of residential units
- number of buildings
- effective year built
- effective building area
- parcel area

The parcel ID number uniquely identifies plots of land which link the various databases presented in this methodology. The FDOR land use codes are used to identify the primary land use by its economic activity. Effective year built is defined as the effective or actual year built of major improvements for a building. The year built provides valuable time series information to estimate trends, and is an essential tool in forecasting number of accounts, building and parcel characteristics, and water use rates.

The effective or adjusted building area is defined as the total effective area of all floors of all buildings on a given parcel. Effective area incorporates economic factors to weight the various building area types found within a parcel, and therefore does not represent true physical area. The FDOR database provides polygon shapefiles delineating every parcel in the State. These polygon shapefiles offer the spatial location of every parcel in the State, allowing simple spatial queries to determine which parcels are within the service boundaries of a given utility. Parcel area is derived using standard GIS tools, and joined to the other parcel information provided in the FDOR attribute data. Parcel area is also calculated and reported by FGDL.

For Gainesville Regional Utility (GRU), the utility boundary was obtained from St. Johns River Water Management District (SJRWMD) at http://www.sjrwmd.com/gisdevelopment/docs/themes.html. This shapefile contained all currently served and future (proposed) utility boundaries in SJRWMD. The currently served GRU boundary was selected for this analysis.

Alachua County Property Appraiser Data

Each of the 67 counties in Florida maintains a Florida County Property Appraisers (FCPA) database that contains the same information as the FDOR database, along with additional attributes that vary from county to county. Attributes of interest in all FCPAs include parcel ID number and heated building area. Parcel ID number is a unique identifier and serves as the link between the FCPA and FDOR databases. FCPA provides the heated areas of buildings in a parcel, defined as all building area under climate control. Unlike effective building area, provided by FDOR, heated area is a physical building area. Heated area is the commonly used measure of the size of the property for real estate descriptions and is measured accurately due to its importance. The Alachua County Property Appraiser database was used since it encompassed GRU. In addition to heated area, the number of bathrooms and bedrooms per building and the presence of a sprinkler system were attributes of interest in the ACPA database. The presence of these fields in all FCPA databases is unknown.

GRU Customer Billing Data

GRU provided monthly customer billing data ranging from 03/2007 through 02/2010 for all served customers. A total of 2,320,880 billing records were provided in the database. This data needed to be linked to the parcel data in the ACPA and FDOR databases. Linking billing data to property data is a time and labor intensive process which is utility specific. Linking GRU billing data to property data including QA/QC took experienced personnel approximately one month to complete. In the GRU database, every billing record can be associated with an installation ID, which represents an individual meter. Each meter is then associated with a Premise ID, which represents a physical location of a meter, or a group of meters. For example, an apartment building may have multiple meters for each apartment in a single location. All of these meters would be assigned to a single premise ID. In order to link Premise ID to Parcel attributes, GRU provided a GIS shapefile containing geocoded spatial points of each Premise ID. This data could then be overlaid on the FDOR parcel shapefiles to determine which Parcel IDs the Premise IDs belonged to. The data was then filtered to analyze only those parcels for the FDOR codes of interest. Records with identical Parcel IDs, FDOR use codes, and Premise IDs were grouped to avoid duplicate usage records from occurring. A total of 33,979 records were associated with Premise IDs occurring in multiple Parcels. These records were excluded since Premise IDs should represent a single location of meters not spread across multiple parcels.

The remaining billing records were then rectified to account for lag time between billing read date and billing month using the procedure described in Dziegielewski & Opitz (2002). Once this was done, usage records for meters with a common Premise ID could be aggregated. Then usage records from multiple Premise IDs on a common Parcel could be aggregated. This resulted in 439,239 monthly usage records for 3,005 parcels which could be linked to attribute data.

NUMBER OF PARCELS, ACCOUNTS, AND RESIDENTIAL UNITS

The “number of customers in the group” needs to be determined in order to estimate water usage for the multi-family sector utilizing Equation 2. For the single family sector, number of parcels can be used to estimate this term since a one-to-one relationship exists between the number of parcels and accounts. However, the multi-family sector could range from having a single account for an entire apartment complex to an individual account for each unit. Due to this inconsistency, the number of residential dwelling units needs to be the fundamental unit of size for the multi-family sector. Since FDOR provides the number of residential units per parcel, it is possible to base water usage at the parcel level in terms of number of residential units. Equation 2 can be more explicitly written for the multi-family sector shown by Equation 3.

$$q = 30.4 \cdot \sum_{i=1}^{m} (a_i \cdot x_i \cdot r_i \cdot n_i) \qquad (3)$$

Where:
q = total multi-family water usage (gallons/month)
a_i = gallons/person/day for parcel i
x_i = persons per residential unit for parcel i
r_i = occupancy rate for parcel i
n_i = number of residential units for parcel i
m= total number of multi-family parcels
30.4 = conversion factor from gallons/day to gallons/month

The number of residential units may not be accurately reported for all parcels in DORUC 3, representing multi-family apartment buildings greater than 10 units. Some parcels in this category are mistakenly reported as having one residential unit per parcel, under representing the actual number of residential units. The heated area per unit can be used to check the validity of the reported number of residential units. The size attributes for seven FDOR use codes in GRU are shown in Table 3. For the GRU dataset, most of the parcels and associated heated area occurred in DORUC 3, 4, and 8 which is consistent with the state data. No cooperatives were in the GRU case study dataset. The number of residential units appears to be underreported for the three retirement homes in GRU. <<Assume about 400 sf/person to estimate units in retirement homes. The statewide data showed that parcels in this category typically contain many units. The heated area to residential unit ratios appear reasonable for DORUC 3, implying that number of residential units was reported correctly by ACPA to FDOR for this use code.

Table 3. Size attributes for GRU dataset

DORUC	FDOR stratum	FDOR description	Total parcels	Percent of total parcels	Total effective area (thousand sf.)	Total heated area (thousand sf.)	Percent of total heated area	Heated area (sf)/parcel	Total res. units	Units/ parcel	Heated area (sf)/unit
3	Multi-family res.	Multi-family – 10 units or more	276	9%	21,000	19,987	80%	72,417	25,987	94.16	876*
4	Single family res.	Condominiums	1,894	63%	2,364	2,363	9%	1,248	1,894	1.00	1,248
5	Single family res.	Cooperatives	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	Multi-family res.	Retirement Homes	3	0%	358	356	1%	118,783	1	0.33	356,349
7	Multi-family res.	Miscellaneous residential	8	0%	9	9	0%	1,175	7	0.88	1,343
8	Multi-family res.	Multi-family – less than 10 unit	810	27%	2,245	2,157	9%	2,663	2,361	2.91	914
28	Commercial	Mobile home parks	12	0%	260	255	1%	21,275	280	23.33	912
		Total	3,003	100%	26,236	25,128	100%	8,368	30,530	10.17	823

* denotes adjusted heated area/unit for DORUC 3 after QA/QC

Relationship between Heated Area and Residential Units

Since the number of residential units is not consistently reported throughout the State, an alternative method to estimate this parameter needed to be developed. Heated area is reported at the building level but can be aggregated to the parcel level. This field is consistently reported as the total heated area per building independent of the accuracy of the number of residential units. The relationship between heated area and number of residential units per parcel for 276 FDOR 3 parcels in GRU is shown in Figure 1. Heated area is provided in the ACPA database, and is not available in the FDOR statewide parcel database. However, the heated area for Florida parcels can be determined based on the effective area provided in the FDOR database (Morales et al. 2010). Like heated area, effective area is consistently reported as the total area per parcel, regardless of the accuracy of number of residential units.

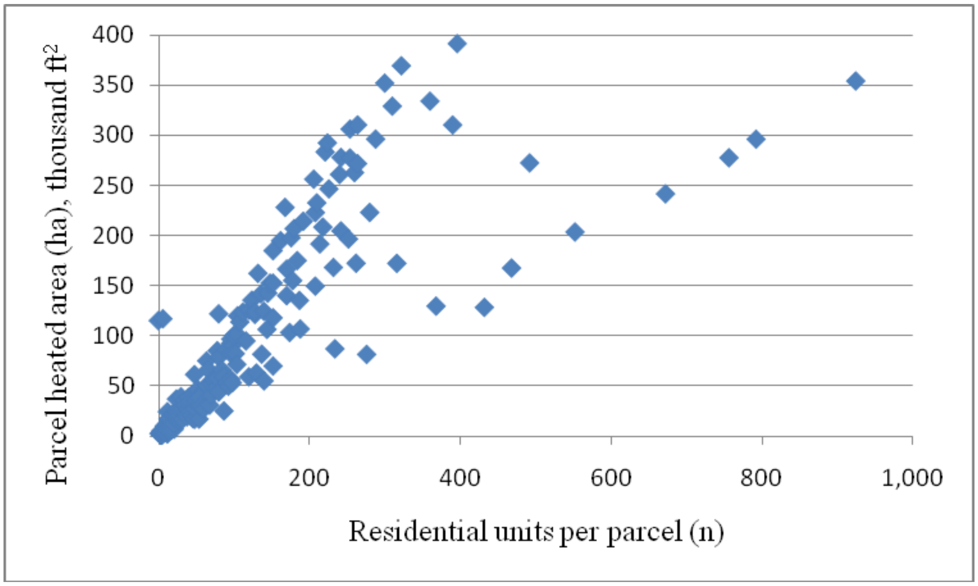

Figure 1. Relationship between heated area and number of residential units per parcel for 276 FDOR 3 parcels in GRU. << SHOW SLOPES ON THE TWO LINES OF 384 AND 876 SF PER UNIT.

As shown in Figure 1, an apparent positive linear relationship exists between heated area and number of residential units. However, the bulk of parcels appear to follow one trend, whereas a small subgroup appears to follow another trend. These few parcels had more units per heated area than the rest. A detailed investigation showed these parcels are large apartment complexes with individual bedroom leasing. For example, the data point at the top right of the chart represents an apartment complex with 924 reported residential units with a heated area of 354,707 ft^2 or 384 ft^2 per unit. This complex also had a reported average 3.06 bedrooms per unit. Assuming the reported number of residential units represents individually leased bedrooms, the actual number of residential units (apartments) is 924bedrooms/3.06 bedrooms per residential unit = 302 residential units. The average heated area per unit then becomes 354,707 ft^2 /302 units = 1,175 ft^2 per unit, a reasonable number for multi-family units. Ten out of the 276 parcels indicative of this trend were removed from the regression analysis. Two data points were removed which reported large heated areas but zero or very few residential units. The resulting 264 parcels were used to develop the relationship between heated area and number of residential units, shown in Figure 2.

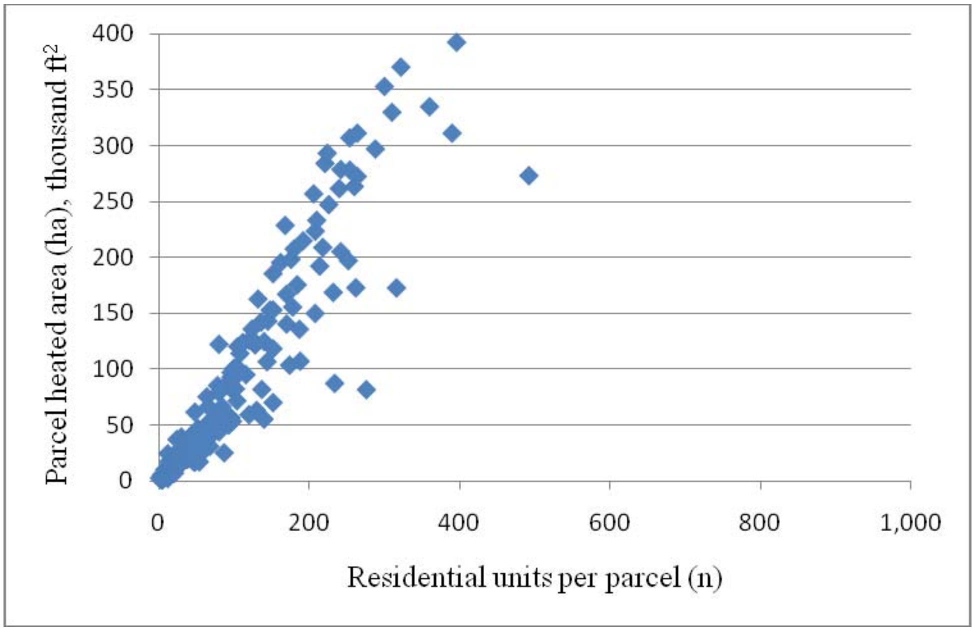

Figure 2. Relationship between heated area and number of residential units per parcel for 264 FDOR 3 parcels in GRU after QA/QC. DELETE FIGURE 2?

Based on this data, the average relationship between heated area and the number of residential units was determined as the sum of heated areas divided by the sum of residential units over all parcels in a given sector, shown by Equation 4.

$$\overline{ha} = \frac{\sum_{i=1}^{m} ha_i}{\sum_{i=1}^{m} n_i} \quad (4)$$

Where:
$\overline{ha}$= average heated area per unit (ft^2/unit),
ha_i = heated area for parcel i (ft^2),
n_i = number of residential units for parcel i, and
m= number of multi-family parcels.

For GRU, $\overline{ha}$= (17,231,699 ft^2)/(19,669 residential units) = 876 ft^2/unit. This average can be used to approximate number of residential units per parcel if only heated area is known.

OCCUPANCY RATE

The long-range transportation plan for the Gainesville urbanized area estimates that the overall present and projected occupancy rate for all residential units is 90% (Corradino Group, Inc. 2005). Multi-family residential units would be expected to have a lower occupancy rate. Thus, it seems reasonable to use 95% occupancy for SFR and a 90% overall occupancy rate based on the Transportation Plan estimate. About 2/3 of the residential units in Florida are single family

(Table 1). Thus, in order to have an overall average of 90% occupancy, the MFR occupancy must be 80% (0.95*2/3 + 0.80*1/3). These estimates can be overridden with local data if available.

PEOPLE PER RESIDENCE

Methods for estimating the average persons per residence (ppr) are discussed in this section. A residence is defined as a single housing unit. Data sources and methods to determine ppr at various levels of aggregation are described.

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 most recent census is being done in 2010. The population survey results are available at the census block level of aggregation. The U.S. Census does not distinguish single family from multi-family residences in calculating the average ppr for a census block. Census block data can be accessed directly from the U.S. Census Web site, http://www.census.gov/, as direct tables or as Geographic Information System (GIS) shapefiles. Direct tables are available for political boundaries such as cities, counties, and states.

Gainesville Regional Utilities (GRU) was used as a test case for determining separate ppr values for SFR and MFR accounts. 2000 Census files were combined with 2009 utility boundaries in GIS to determine the 1,819 census blocks that are in GRU as of 2009. Traffic Analysis Zones (TAZ's) are used for transportation planning. There are 453 TAZ's in the Gainesville metropolitan area (Corradino Group, Inc. 2005). Thus, for Gainesville, there are about four census blocks per TAZ. Each account was assigned to the census block that included the centroid of its parcel boundary.

The 2000 Census estimate of persons per house is determined for the combination of SFR and MFR parcels in each block. Population data from the 2000 Census tell how many people resided in this Census block in the year 2000. The FDOR data tell how many developed parcels existed in this block in the year 2000. The 1,819 Census blocks were divided into the three categories shown in Table 4. A total of 1,172 out of 1,819 Census blocks located within GRU as of 2009 had only SFR parcels with an average of about 20 residences per Census block. The average persons per residential unit for this category is 2.55. Similarly, 175 out of the 1,819 Census blocks had only MFR parcels with an average of 77 residential units per Census block. The average persons per residential unit was 1.94. The remaining 472 Census blocks were hybrids with a blend of SFR and MFR housing. The reported average persons per unit for hybrid Census blocks can be expressed as a convex combination of SFR and MFR households. If one assumes an SFR/MFR ratio = 2.55/1.94 = 1.31 for all Census blocks, then it is possible to calculate the SFR and MFR persons per residential unit for each Census block, utilizing Equations 5 and 6.

$$X_b = \lambda_b X_{b,SFR} + (1-\lambda_b) X_{b,MFR} \tag{5}$$

$$\frac{X_{b,SFR}}{X_{b,MFR}} = 1.31 \tag{6}$$

Where:

X_b = reported average persons per residential unit for hybrid census block b,
$X_{b,SFR}$ = average persons per residential unit for single family residences in census block b,
$X_{b,MFR}$ = average persons per residential unit for multi-family residences in census block b, and
λ_b = percentage of single family residential units in census block b ($0 \le \lambda_b \le 1$)

This procedure is used for all Census blocks. The resulting average ppr's for SFR and MFR in the hybrid Census blocks are shown in Table 4.

Table 4. Determination of average persons per residential unit at the census block level of aggregation for Gainesville, Florida

Item	Category	Census Blocks in GRU as of 2009	Parcels as of 2000	Residential Units as of 2000	Average Persons per Residential Unit as of 2000	Residential Units per Census Block as of 2000
Census Blocks With Either SFR or MFR	Single Family Residential	1,172	23,089	23,203	2.55	19.8
	Multi-Family Residential	175	2,711	13,497	1.94	77.1
	Total Residential	1,347	25,800	36,700	2.32	27.2
Census Blocks With Both SFR or MFR Present	Single Family Residential		17,439	17,698	2.44	
	Multi-Family Residential		6,994	29,272	2.15	
	Total Residential	472	24,433	46,970	2.26	99.5
All Census Blocks	Single Family Residential		40,528	42,769	2.39	
	Multi-Family Residential		9,705	40,901	2.18	
	Total Residential	1,819	50,233	83,670	2.29	46.0

In addition to the census, The Department of Housing and Urban Development (HUD) and the U.S. Census Bureau conduct American Housing Surveys for selected cities at the individual parcel level (Dziegielewski and Opitz 2002). Data from the American Housing Survey (AHS) are 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 scaled proportionally until the estimate of total number of residencies matches the values from the most recent U.S. Census count of residences. The AHS includes average household sizes for SFRs, MFRs and mobile homes as shown in Table 5 (U.S. Census 2009). Average household size has remained stable since 1983; thus recent census estimates are directly applicable and do not need to be adjusted for growth trends (Friedman et al. 2010).

Table 5. People per residence from the 2007 Tampa American Housing Survey

Category	1,000 units	Persons/ unit
Single Family Residential	706.8	2.51
Multi-family Residential	227.1	1.84
Mobile Homes	141	2.04
Total	1074.9	
Weighted Average		2.31

MONTHLY WATER USAGE TRENDS

The GRU customer billing data was analyzed for monthly trends. Monthly water usage for 2008 and 2009 was analyzed representing complete years of available customer billing data. Only DORUC 3, 4, and 8 were analyzed since these represented the majority of customers. The average precipitation in Gainesville from 1900 to 2009 was 51.51 inches. The average precipitation for 2008 was 39.72 inches, the 13^{th} driest of the past 110 years. The average precipitation for 2009 was 46.90 inches, the 37^{th} driest of the past 110 years. Thus, analyzing 2008 and 2009 data reflect drier than average conditions, although other factors should be considered. The monthly time series normalized per residential unit for each use code is shown in Figure 2. Summary statistics for the three relevant use codes is shown in Table 6.

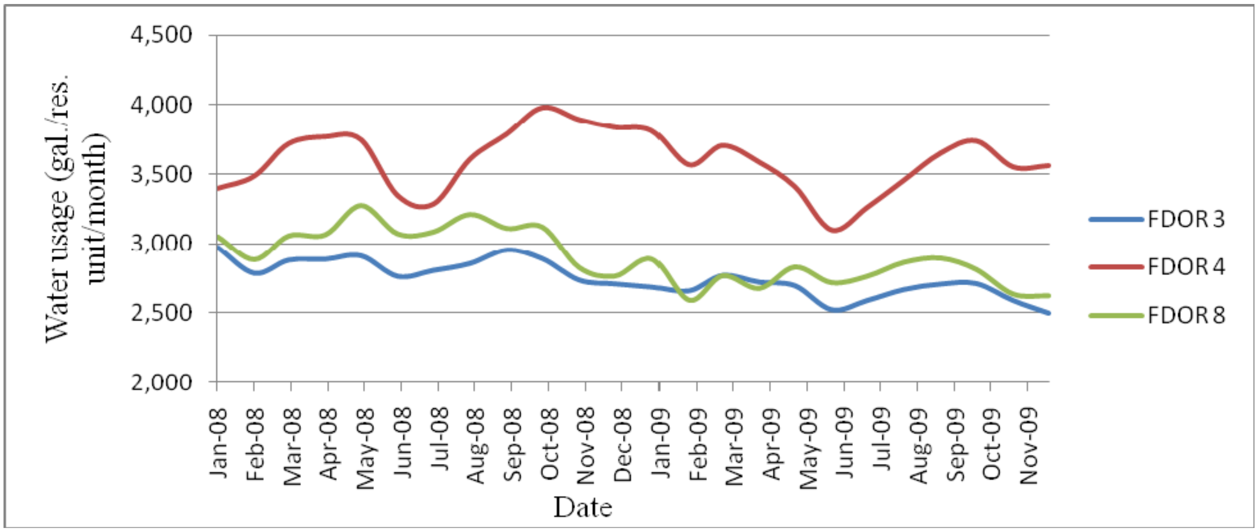

Figure 2. Average monthly water usage from Jan 2008 through Dec 2009 for DORUC 3,4, and 8 in GRU

Table 6. Summary water usage statistics from Jan 2008 through Dec 2009

DORUC	3	4	8
Average usage (monthly gal./res. unit)	2,750	3,593	2,899
Standard deviation (monthly gal./res. unit)	130	221	196
Coefficient of variation	0.05	0.06	0.07
Peak month usage (monthly gal./res. unit)	2,976	3,981	3,277
Peak to average ratio	1.08	1.11	1.13
Minimum month usage (monthly gal./res. unit)	2,498	3,096	2,589

DORUC 3 and 8 represent apartment buildings and exhibit similar usage trends. Both show a slight downward trend in usage from 2008 to 2009. DORUC 4, representing condos, uses more water per unit per month than apartment buildings, most likely due to more people per unit. Condos also showed slightly more variability than apartment buildings; however seasonal usage is not significant for any of the use codes.

Indoor vs. Outdoor Usage

The average per capita water usage for each use code can be determined from the GRU customer billing data using Equation 3. The number of residential units was previously shown in Table 3. An average of 1.94 people per residence with an 80% occupancy rate was assumed for apartment buildings. Condos were assumed to exhibit an average household size similar to single family homes; thus an average of 2.55 people per house was assumed as shown in Table 4. An occupancy rate of 80% was used since the long-range Gainesville metropolitan transportation plan considers condos multi-family dwellings. Assuming 30.4 days per month, average per capita usage could then be determined as shown in Table 7.

Table 7. Summary statistics of water usage for FDOR 3,4, and 8 in GRU

DORUC	3	4	8
Avg. usage (monthly gal./res. unit)	2,750	3,593	2,899
Min. month usage (monthly gal./res. unit)	2,498	3,096	2,589
Average persons per residence	1.94	2.55	1.94
Occupancy rate	0.8	0.8	0.8
Avg. usage (daily gal./person)	58.29	57.94	61.44
Min. month usage (daily gal./person)	52.95	49.92	54.87

Indoor and outdoor gallons per capita per day (gpcd) can be determined by hydrograph separation using Equation 7.

$$Q_{out}=Q_{tot}-Q_{in} \quad (7)$$

Where:
Q_{out}= outdoor usage (gpcd),
Q_{tot}= total usage (gpcd), and
Q_{in} = indoor usage (gpcd).

MFR per capita water use should have many similar characteristics to SFR water use that has been well studied. SFR indoor water use for existing homes is in the range of 60-70 gpcd. Indoor usage can also be estimated using the minimum month method, which assumes that the minimum month of usage on record reflects indoor only usage. (Dziegielewki & Opitz 2002, Friedman 2009). The average usage for all three use codes is close to 60 gpcd, indicating that little outdoor usage occurs.

Further analysis of the MFR GRU dataset indicated no sprinkler systems were installed for any MFR parcel. Accordingly, indoor usage can be assumed to be 60 gpcd for the MFR sector with outdoor usage representing an insignificant portion of water usage. Condo parcels only contain the physical structure and do not contain common areas. From the GRU case study, it appears that common areas are designated as vacant in FDOR and receive no property attributes. Outdoor water usage associated with condos may exist on these parcels.

This methodology provides a viable top-down approach toward estimating MFR water usage. However, these estimates can be improved by evaluating end uses, as explained in the next section.

INDOOR END USE ESTIMATES

An alternative and more detailed formulation to determine sectoral water usage involves an end use analysis of all water using devices for the sector. This bottom-up methodology provides a more accurate determination of water usage. An end use inventory of all indoor water using fixtures can be directly determined based off number of bathrooms per residential property from appraiser data. Effective area provided in the FDOR database can be used to estimate heated area and the number of bathrooms (Friedman et al. 2010). Residential units then can be grouped based on number of fixtures per unit and fixture efficiency type. Water usage per fixture can then be determined based on frequency of use assumptions and type of fixture determined utilizing FDOR effective year built and assumptions of fixture service life assumptions, shown in Equations 8 and 9 (Friedman et al. 2010). Estimates of service lives for a variety of end uses are available in National Association of Home Builders (2007), Maddaus (2009), and Green (2010).

$$\alpha_{ij} = (b_{ij} \cdot f_{ij} \cdot x_{ij}) / d_{ij} \quad (8)$$

$$q = 30.4 \cdot \sum_{j=1}^{4} \sum_{i=1}^{m} (\alpha_{ij} \cdot y_{ij}) \quad (9)$$

Where:
q = single family residential indoor usage (gal/mo)
b_{ij} = fixture efficiency type (e.g., gal./flush) in subgroup i for fixture j
f_{ij} = frequency of use (e.g., flush/person/day) in subgroup i for fixture j
x_{ij} = persons/residential unit in subgroup i for fixture j
d_{ij} = number of fixtures/residential unit in subgroup i for fixture j
α_{ij} = daily indoor usage rate (gal./fixture/day) in subgroup i for fixture j
y_{ij} = total number of fixtures in subgroup i for a fixture j
m = total number of subgroups for fixture j
30.4 = conversion factor from gal/day to gal/month

An end use analysis was performed on the GRU dataset to estimate water usage for DORUC 3, 4, and 8. This analysis was performed at the parcel level. Data was then aggregated into subgroups based on fixture efficiency type. The estimated mix of fixtures in 2009 for GRU, based on a service life of 40 years for toilets and showerheads, 10 years for clothes washers, and 15 years for faucets, is contained in Table 8. This data could be aggregated into subgroups based on number of fixtures per residential unit for more detailed conservation analysis.

Table 8. Fixture inventory for DORUC 3, 4, and 8 in GRU based on end use analysis

Fixture efficiency group	Toilets	Showerheads	Clothes washers	Faucets	Total
Pre 1983	11,220	11,113	0	0	22,333
1983-1994	17,785	17,637	0	0	35,422
1995-2008	48,970	48,141	19,747	108,217	225,075
Total	77,975	76,891	19,747	108,217	282,830

Water usage (monthly gal./unit) was determined for all 2,980 parcels in DORUC 3, 4, and 8 in GRU based on the end use analysis methodology. A weighted average was utilized to determine the average usage per DORUC per fixture as shown in Table 9.

Table 9. Average water usage (monthly gal./unit) for DORUC 3, 4, and 8 in GRU based on end use analysis

DORUC	Toilets	Showerheads	Clothes washers	Faucets	Total	Billing data
3	868	644	481	717	2,709	2,750
4	885	838	1,030	942	3,695	3,593
8	1,221	654	650	717	3,242	2,899
Total	897	657	528	731	2,812	2,814

Billing data was previously shown to consist of mostly indoor usage. Thus the total water usage from indoor end use estimates should be close to recorded billing data. A comparison of total water usage from indoor end use estimates to billing data shows that the end use assumptions are reasonable. Indoor end use water usage matches closely with billing data for DORUC 3 and DORUC 8 has higher predicted usage from end use estimates than recorded billing records. This could indicate the toilet service life for these parcels is shorter than the assumed 40 years since average toilet usage appears high, with a predicted 38% of indoor usage. In addition, leakage and other indoor uses could increase the total end use estimate. Leakage could be significant on the customer side of the meter in which case other assumptions may need to be adjusted to accurately predict indoor usage. However, the fixture frequency may be lower than predicted as occupancy of multi-family dwellings is less than single family, and fixture frequencies were based on single family residential studies.

ANALYSIS OF CONSERVATION OPTIONS

Multi-family conservation options involve fixture retrofits or individual customer metering. The conservation savings of indoor fixture retrofits for multi-family residencies can be predicted directly from the end use analysis. The savings are determined as the difference of water usage from existing and proposed fixtures. A production function can be developed to order fixture replacement from most to least water savings. A linear program can then be applied to maximize the economic benefits of fixture retrofits. Friedman et al. (2011) discuss this procedure in detail for single family residential toilets. This algorithm can be applied across multi-family fixtures as well as other sectors.

Multi-family water usage can also be reduced by implementing a sub-metering program. Virtually all SFR homes in Florida are metered and meters have been shown to reduce water use, especially outdoor water use. On the other hand, only about 5 to 10% of MFR individual units (apartments, condominiums, etc.) are metered. Rather, water use is metered for the entire MFR parcel and is divided among residents. Thus, the occupants of the individual units have no direct incentive to save water. One conservation BMP is to install sub-meters so that the water use at the individual unit level can be measured and the occupant billed for their actual water use.

Mayer et al. (2005) conducted a national study of MFR water use including the expected effect of sub-metering on water use. Hillsborough County Water Resources Services was one of 13 cities that were studied. Survey data and historic billing records were used to estimate MFR water use patterns. Mayer et al. (2005) also present a summary of other studies that estimated the impact of sub-metering. They estimate savings of 15.3% or 21.8 gallons per unit per day (gpud) with a range from 15 to 48 gpud. This savings can be the result of a variety of actions including: fixing leaks, taking shorter showers and baths, reduced faucet use, reduced use of clothes and dish washers. It is important to assign these sub-metering savings to an end use to avoid double counting the impact of sub-metering vs. an end use retrofit.

SUMMARY AND, CONCLUSIONS

The multi-family sector represents a significant homogeneous group of water users and should be evaluated independently from other sectors including single family homes. In contrast to existing methods, FDOR statewide parcel data, along with default coefficients based on the detailed GRU case study, can be used to accurately estimate multi-family water usage for Florida utilities. Multi-family water usage was shown to be mostly indoor, with an average per capita usage rate of 60 gpcd. End use analysis utilizing the FDOR parcel data accurately predicted indoor water usage for GRU. This methodology could be applied to any utility in Florida.

Seven FDOR land use codes were analyzed as potential multi-family land uses. DORUC 3 and 8 represent apartment buildings with an average heated area per unit between 876 and 1,234 square feet, respectively, an occupancy rate of 80%, and an average of two people per residence. In addition, parcels in these use codes represent entire apartment complexes including common areas, parking, etc. DORUC 3 and 8 also have a per capita indoor usage rate of 60 gpcd, with minimal outdoor usage. These characteristics can be used to define a homogenous multi-family sector. DORUC 6 and 7 representing retirement homes and miscellaneous residential have similar characteristics to apartment complexes and can be grouped in the multi-family sector. DORUC 4, representing condos, has a similar heated area per unit to apartment buildings. However, condos have an occupancy rate and average people per house more similar to single family homes. Like single family homes, condos are defined by each residential unit, although outdoor usage occurs in common areas delineated by separate parcels. DORUC 5, representing cooperatives was not analyzed in detail, but has similar parcel definitions and property characteristics to condos. Although these use codes exhibit some multi-family characteristics, the current FDOR single family stratum can be used to include condos and cooperatives. DORUC 28, representing mobile home parks, exhibited traits similar to other multi-family use codes, and should be grouped with the multi-family stratum rather than the current classification into the commercial stratum.

Multi-family conservation options involve fixture retrofits or individual customer metering. The conservation savings of indoor fixture retrofits for multi-family residencies can be predicted directly from the end use analysis. The savings are determined as the difference of water usage from existing and proposed fixtures. Multi-family water usage can also be reduced by implementing a sub-metering program. This is a viable option since few multi-family units are currently sub-metered. This study was done as part of the Conserve Florida Water Clearinghouse program.

REFERENCES

Corradino Group, Inc. 2005. Gainesville Urbanized Area 2025 Long-Range Transportation Plan Update. Prepared for the Metropolitan Transportation Planning Organization, Gainesville, FL http://www.ncfrpc.org/mtpo/publications/LRTP2025/Y2025LRTPU.pdf

Dziegielewki, B. & Opitz, E.2002. Water Demand Analysis. Chapter 5 in Mays, L. Ed. Urban Water Supply Handbook, McGraw-Hill, NY

Green, D. 2010. Water Conservation for Small and Medium Sized Utilities. AWWA, Denver, CO

Florida Department of Revenue. 2009. User's Guide For 2009 Department Property Tax Data Files. Draft Document.

Friedman, K. 2009. Evaluation of Indoor Urban Water Use and Water Loss Management as Conservation Options in Florida. M.E. Thesis, Dept. of Environmental Engineering Sciences, U. of Florida, Gainesville, FL

Friedman, K. , Heaney,J. ,Morales, M., and J. Palenchar. 2011. Water Demand Management Optimization Methodology. Accepted for publication, *Journal of American Water Works Association*.

Maddaus, W. & Maddaus, L. 2006. Water Conservation Programs-A Planning Manual. American Water Works Association Manual of Water Supply Practices M52, AWWA, Denver, CO.

Maddaus, W. 2009. Conservation Technical Analysis. Memorandum to East Bay Municipal Utility District, 40 p. http://www.ebmud.com/sites/default/files/pdfs/Conservation_Memo.pdf

Marella, R.L. 2008. Water Use In Florida, 2005 and Trends 1950-2005. U.S. Geological Survey Fact Sheet, http://pubs.usgs.gov/fs/2008/3080/#Domestic-Self-Supplied Water Use

Mayer, P. et al. 2005. National multiple family submetering and allocation billing program study. Aquacraft, Inc., Boulder, CO

Morales, M. Heaney, J., Friedman, K., & J. Martin. 2010. Parcel-Level Methodology for Estimating Commercial, Industrial and Institutional Water Use. *Journal of American Water Works Association,* 103:6, p. 84-96..

National Association of Home Builders. 2007. *Study of the Life Expectancy of Home Components.*

Solley, W., Pierce, R., and Perlman, H. (1998). *Estimated Water Use in the United States in 1995*. U.S. Geological Survey Circular 1200.

U.S. Census Bureau. (2009). Current Housing Reports. Series H170/07-62, American Housing Survey for the Tampa-St. Petersburg Metropolitan Area: 2007.

U.S. Census Bureau (2010). State and County QuickFacts. 2010. Florida Quick facts. http://quickfacts.census.gov/qfd/states/12000.html