Florida Automated Water Conservation Estimation Tool Overview

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The St. Johns River Water Management District's Florida Automated Water Conservation Estimation Tool (FAWCET) was developed to estimate the amount of water conservation potential in the 18-county district (Castaneda, Blush; *Florida Water Resources Journal*, 2011 and 2012). The tool uses account-level water use data provided through collaboration with other utilities and provides a standardized county appraiser geodatabase and census data to disaggregate and analyze water use by parcel. By joining three data sets and making basic assumptions regarding use and existing fixtures (baseline), FAWCET captures the potential for reducing demand through the use of replacement fixtures and more efficient best management practices (BMPs).

The goal is to produce estimates for the District's water supply plans from a planning region level and to develop implementable utility-level water conservation plans. The FAWCET development consists of a data development component and a model development component; together, these two components support four important initiatives for the District: the North Florida Regional Water Supply Partnership, the Central Florida Water Initiative (CFWI), the development of minimum flows and levels prevention, and recovery strategies for District springs.

The FAWCET is used to identify water conservation/demand management projects that will enhance existing plans for alternative and traditional water supply projects. The FAWCET data component will be used to develop water use estimates by parcel for calculating recharge in the District groundwater modeling efforts. The tool has been used internally as a conservation goal setting and program planning tool. With a few adjustments, FAWCET has the potential to be used, not only for water conservation, but also as a water supply project optimization and water quality program and project planning tool.

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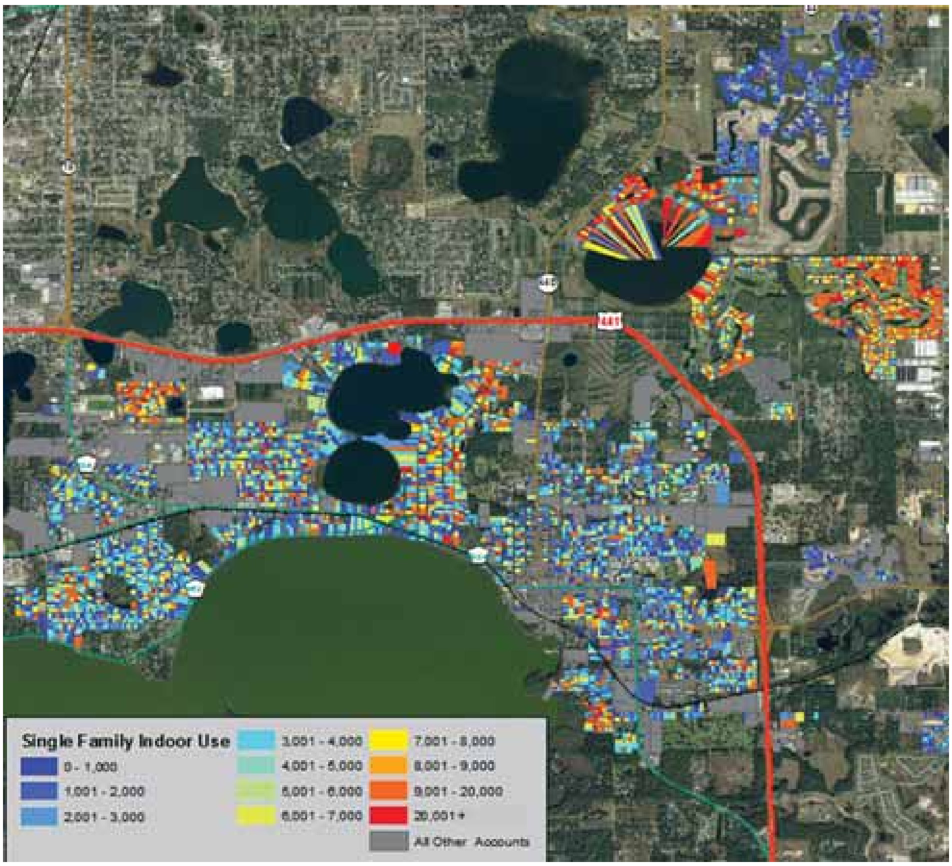

Figure 1. A heat map of Mt. Dora indoor water use is developed by assuming the indoor base use is the same as the minimum-month use. This is usually a December or January winter-use volume.

The model component is a spreadsheet in Microsoft Excel, which has been converted into PuLP/Python, which is an open-source, linear programming language, with the goal of compatibility on a variety of machines and the capability to run millions of accounts. For the purposes of this article, the tool's logic will be described using the Microsoft Excel/Solver-Studio version. The details regarding the model component will be covered after the data development component.

Data Development

The FAWCET uses three separate databases available in Florida, including a standardized county appraiser database funded by all five of the state's water management districts. The data set contains a physical address field and dimensions of the building and property used by FAWCET to estimate existing fixtures. The Department of Revenue (DOR) code is used to standardize the land use across a wide variety of utilities in Florida. Limited census information, such as household population, is used to determine gal per capita per day (gpcd) at a census-block level. Once the databases have been joined, the util-

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ity billing information provides a range of fields useful to the utility and FAWCET.

The most useful field for FAWCET is the monthly consumption field, which is further processed by the District to separate hose irrigators from inground irrigators. The minimum-month method is used to determine the base use and represents a household's indoor use. This is the lowest use, or minimum-month use, throughout a typical year (usually December or January). If the difference between the minimum-month and the peak-month (that month with the highest consumption, which is usually April or May) is greater than 10 thousand gal, that household is determined to be an inground irrigator. This method was previously determined (Jones Edmunds, 2010) and has been continually confirmed to be a reliable method for determining inground irrigators through the comparison of separately metered data. The process of separating indoor use from outdoor use is instrumental in developing parcel-level water use geodatabase heat maps (see Figure 1).

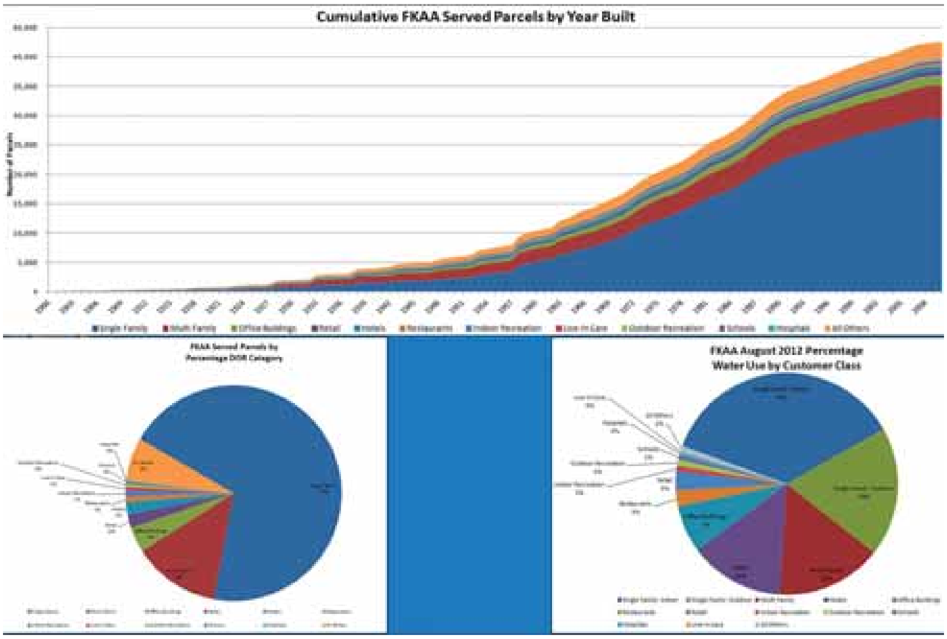

Figure 2. The Department of Revenue codes can be used to disaggregate data and show their proportions in number or by water use. Sector water use proportion can be shown over time, allowing for hindcasting and forecasting calibrated use.

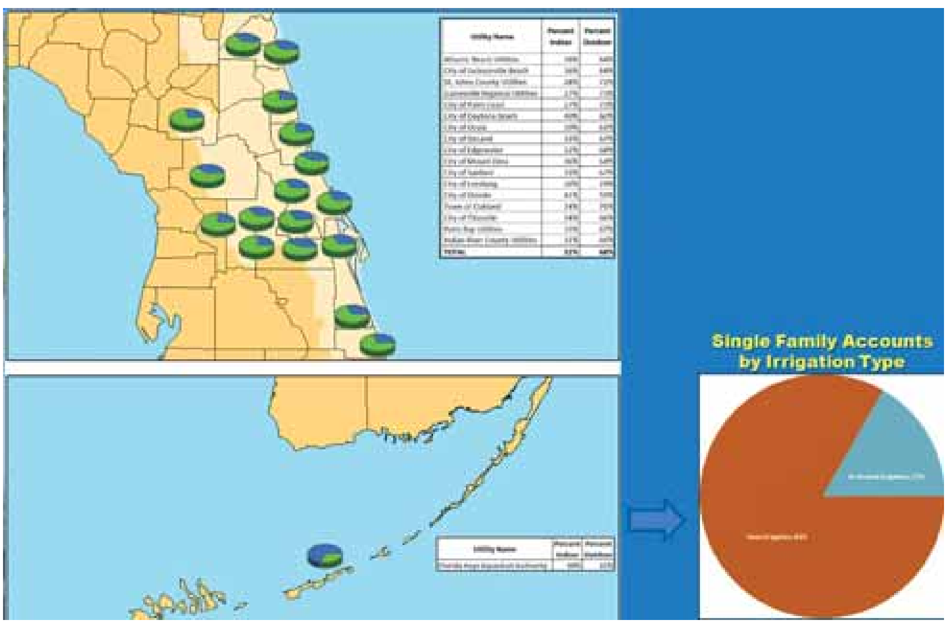

Figure 3. The FAWCET can determine the split between outdoor and indoor use. The percentage split in the District is 70/30, while it is 30/70 in the Florida Keys.

The DOR code allows FAWCET to disaggregate account-level parcels and its water use to a greater degree than the rate category used by utilities; however, the rate category provided by a utility can be preserved as part of the data-joining process. A percentage of accounts by DOR code provide a disaggregated view of the amount (the customer makeup) of DOR code types.

Most utilities serve a unique mix of sectors. The DOR water use by type is represented proportionally, along with the newly developed outdoor use (see Figure 2). The build date allows water use to be represented proportionally for purposes of hindcasting or forecasting. When forecasted, FAWCET uses traditional gpcd methods of determining water use projections to calibrate the resulting water use, such as monthly operating reports (MOR) combined with Bureau of Economic and Business Research (BEBR) population projections.

The FAWCET data can be used to answer the burning question of interest to utilities and water planners: What percentage of my service system's use is outdoor use? The FAWCET data leverages either separate metered data or estimated inground irrigators to determine the percentage of water use between indoor and outdoor use. This number is 70 percent outdoor versus 30 percent indoor within the District according to District-provided data (see Figure 3). In other areas outside of the District, that proportion may be reversed, as in the Florida Keys.

The FAWCET relies on a benchmark approach to estimate water use, previous to the development of the current data sets used. This approach utilizes results from national studies that associated square footage of a building or lot with a use per sq ft to determine indoor and outdoor use, respectively. This step was taken early in the creation of FAWCET in order to demonstrate the approach for developing FAWCET to the District's utility partners. Since then, the District has found actual volumes to be more effective for estimating water use. Actual water use can then be used to develop proxy data. This approach is borrowed from the electric utility industry.

The FAWCET data represents residential water use as a percentage of customers (the y axis) at each level of consumption (the x axis) using the load profile for several utilities (see Figure 4). Load profiles and weighted average

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load profiles are determined for separate indoor and outdoor residential uses. The percentage of billed, low, average, and high customers is information water utility directors keep in their back pocket. Through a simple interview, one could build a distribution scenario on a paper napkin over breakfast from the knowledge of a utility director's residential customers. Utility director's vast knowledge of their systems is precisely why the District partnered with them to develop FAWCET. While it is conceivable that a decent estimate can be derived through the knowledge of a water system director, the District takes a more quantitative approach by deriving a weighted average distribution from account-level utility data provided by up to 26 utilities in the District.

The load profile is a distribution of the percentage of residential customers at each level of consumption. The load profile is instrumental for developing high-level water conservation estimates, while actual account-level data is preferred for the development of implementation plans. Benchmark-derived water use estimates are not typically developed by utilities, while water volumes are routinely developed from meter readings in order to bill each customer. Therefore, results from the data and modeling components of FAWCET are represented as volumes, which can then be targeted by utilities. With the added step of separating indoor from outdoor use, using the minimum-month method, average monthly indoor and outdoor water use totals can be calculated by the utility.

In the absence of actual data, FAWCET continues to rely on benchmark-derived data for estimating commercial, industrial, and institutional (CII) uses, but the CII cannot be represented by load profiles for lack of a large number of data points. While the previous benchmark approach the District used tended to target large homes and large lots, the new approach targets the distribution of high and moderately high water users, regardless of home size or the year of construction. The load profile approach for the development of residential monthly data represents an improvement on the previous residential benchmark approach, while similar improvements are developed in CII. The improvement in CII parcel-level water use estimates will likely come from relating residential development to CII development, excluding industrial.

Due to very large variations, FAWCET does not try to estimate outdoor use for CII or multifamily units and makes no attempt to capture process water uses. The CII benchmark data used by FAWCET consider only the indoor domestic uses within the building. Most of these uncalculated uses are accounted for in the calibration process and represent a minute fraction of use. The FAWCET can only be as good as the data and the assumptions on which it depends. It's with this idea in mind that work continues in earnest to continuously refine the FAWCET data sets.

The development of benchmark-derived data sets is by no means a new science. There have been many studies developed through the U.S. Environmental Protection Agency (EPA) and the Water Research Foundation, particularly work involving the measurement of wastewater and meter flows and CII water use by various analytical means. Many of these approaches, particularly for CII, are described in the *Handbook on Water Use and Conservation* (Amy Vickers, 2001). This work continues to be developed through the use of business data and economic information, relating the number of employees, bed days (in the case of hospital use) and occupancy rates (in hotels), to water use where appropriate. Where actual data is not available for CII, FAWCET depends on benchmark studies developed previously and improved through District utility-data calibrations. The benchmarks are multiplied to the square footage of the heated areas of the building, by DOR code. As actual CII data is accumulated, the benchmarks continue to be refined and generalized across the District, and can be regionalized when needed.

District staff has developed large geodatabases using the load profiles for residential and benchmark approaches for CII; this allows FAWCET to be used outside of the District boundary (see Figure 5). In cases where the state does not have a standardized county appraiser data base, such as Georgia, South Carolina, and Alabama, geodatabase development methods have been modified to rely more on census and national land use data sources. The result of using these approaches is a generalized heat map of separately-derived indoor and outdoor water use. The data set used is residential, monthly indoor and outdoor water use by parcel, from January 2000 to December 2012 (see Figure 6). The process is unprecedented by its geographic scope. It represents a first step in characterizing a range of water use volumes and their seasonality.

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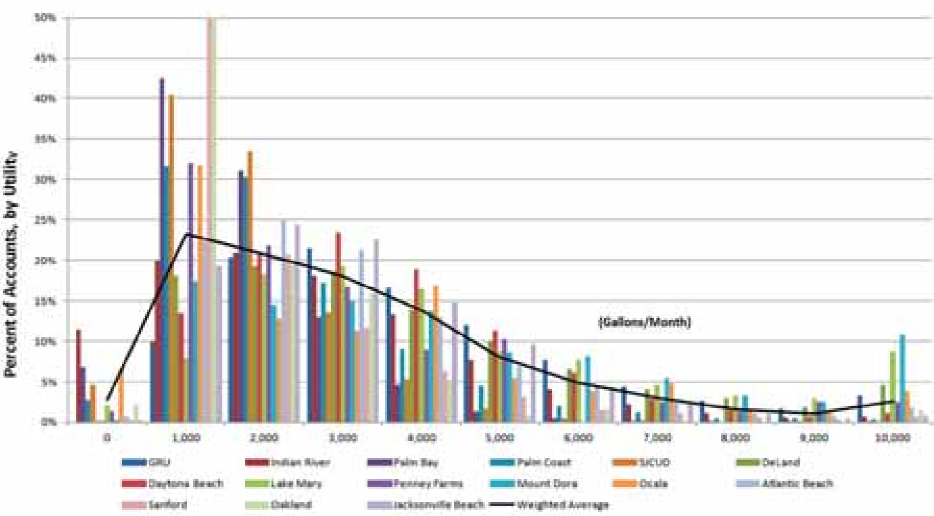

Figure 4. The process for developing a weighted average water use profile for utilities, in cases where no actual account-level data has been provided.

Figure 5. The FAWCET water use by parcel geodatabase has been developed using load profiles and benchmarks (where available). Census information and the national land cover database are used where needed and consist of four states in whole or in part.

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Linear Programming Tool

The District used linear programming techniques to create FAWCET, which estimates the potential for water savings throughout the District by demonstrating the impact of implementing BMPs. This involves upgrading indoor and outdoor fixtures to more efficient ones and conducting audits on high-water-use accounts (Castaneda, Blush; 2012). Originally designed to optimize water savings for a given budget, FAWCET can now maximize energy savings and calculate the benefit—cost ratio (BCR) from the perspective of the utility and any project contributors, among many other options.

Each individual residential and CII account is classified into one of five different building usage types: single-family, multifamily, industrial, institutional, and commercial. The model uses either real data or the randomly assigned weighted average load profile data, square footage, DOR code, and the age of the building to estimate the indoor and outdoor water usage for each account. The indoor water consumption is proportional to the number of fixtures that consume water, such as toilets, washing machines, and kitchen faucets. The outdoor usage indicates the type of irrigation system present in the account; for example, whether there is an inground irrigation system or if a hose is used (Castaneda, Blush; 2012).

The optimization identifies the fixtures that need upgrading, potential water savings, and the cost of implementing these changes, including estimates of the potential savings to water, wastewater, and energy bills. Incentives are also calculated and viewed from the perspective of the utility, the District, or any other contributors to the development of a water conservation program, such as an energy company. The FAWCET relies heavily on reasonable assumptions regarding account use and base conditions before applying a separate set of reasonable assumptions for replacement BMPs and all of the accompanying costs and benefits.

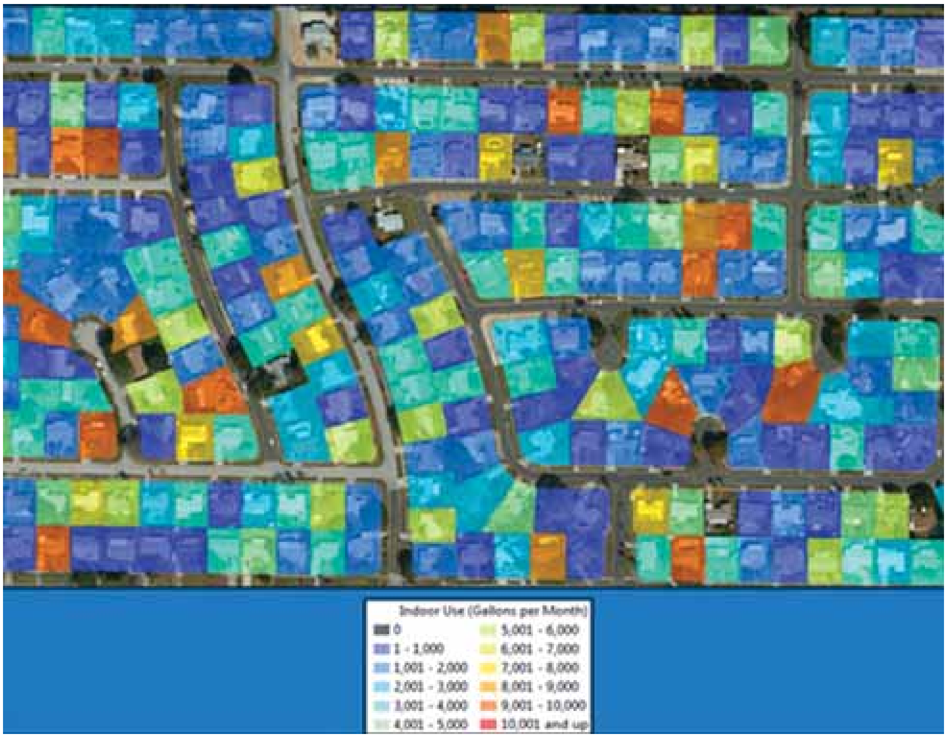

Figure 6. A neighborhood-level view of water use distributed randomly. This provides a conceptual idea of the use and captures the distribution of the data, which is then input into FAWCET for processing. A sample of any of the residential data should produce a similar weighted average distribution developed through the use of 16 or more utilities.

Category	Year Built	Plumbing Code
BO1	1984 and earlier	Pre plumbing standard
BO2	1985 to 1993	National plumbing code
BO3	1994 to present	Federal Energy Act
BO4	future	Current efficiencies assumed

Figure 7. Classification of fixture efficiencies by build-out condition (Castaneda, Blush; 2012).

Accounts

The FAWCET focuses mainly on high-water-usage accounts in the District, which are classified into the five building usage types. Once the type of site is identified through the DOR code, FAWCET determines what proportion of water consumption (indoor or outdoor) is used in an average month. This allows the right type of fixture upgrades to be associated with each account, beginning with single-family, which is the largest water consuming group.

Single-Family Methodology

A single-family account represents a free standing residential building. The water consumption data collected for these accounts is used to estimate indoor and outdoor water consumption. The amount of water expended outdoors is determined by subtracting the minimum month of consumption from the peak month of consumption. The indoor water consumption is proportioned into the amount of water consumed by each water-related fixture, allowing for greater focus on specific indoor fixtures, while outside, the focus is on upgrading or properly maintaining the entire irrigation system. This separation into percentage of end-use volumes allows end-use strategies to become more focused (Castaneda, Blush; 2011). The single-family category requires extra processing to separate indoor from outdoor use, while multifamily use (due to large variations in outdoor use) are not considered by FAWCET to be substantial irrigators.

Multifamily Methodology

Multifamily buildings, such as apartments, townhouses, and condominiums, are used to house typically more than four families. The water conservation potential for these buildings is separated into single units. This is difficult as not all accounts are individually metered. An average consumption for each unit is defined for multiple families that use a single master meter. This is determined by dividing the total water volume by the number

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of units in the building. The number of fixtures in each unit is then established. The number of a type of fixture (e.g., toilets) a unit contains is estimated by considering how many fixtures there would be per sq ft of building area. All multifamily dwellings and CII are classified as nonirrigators (Castaneda, Blush; 2011).

Commercial, Industrial, and Institutional Methodology

The water consumption for these categories varies too much by customer class, and in some cases, process; therefore, FAWCET's main focus is on indoor use by employees and indoor fixtures such as toilets, urinals, kitchen faucets, etc. These customer classes are considered to be nonirrigators until further studies can determine a consistent amount. As with single-family and multifamily buildings, the water used by each end use is estimated as a percentage of the total water consumption (Castaneda, Blush; 2011). The FAWCET database includes the year the building was built and is used to determine each building's current fixture efficiency

Account Fixture Efficiencies

The efficiency of fixtures in an account is dependent on the year in which a structure was built. This is due to original fixtures in a property required to be built in accordance with federal water efficiency plumbing code standards. The data are broken out into four different categories, which are defined in Figure 7. This information, combined with the useful life and assumed flow rates according to the plumbing standard, allows for a reasonable estimation of base conditions. The useful life of fixtures is used to make a reasonable and conservative estimation of fixture upgrades or passive replacement due to remodeling.

Fixture Upgrades

The objective of the model is to assign more efficient fixtures or management strategies to each account's current conditions in order to maximize water savings given a fixed budget. The strategies relating to indoor water savings are very different from those for outdoor conservation. While indoor water-saving strategies depend on building age and involve replacing particular fixtures (such as toilets and shower heads) with more efficient versions, outdoor approaches are more generally focused on waterwise landscaping and more efficient irrigation systems (Castaneda, Blush; 2011).

Building Age

The building category and age of a property is used to estimate the original efficiencies of its fixtures. As fixtures reach the end of their useful life and are replaced over time on the property due to remodeling, wearing out, and malfunctions, the passive replacement of fixtures is determined. This is achieved by dividing the difference between the current year and the year the property was built by each device's life (Castaneda, Blush; 2012). This process is a very conservative approach in that it assumes all BMPs are replaced at the end of their useful life. An adjustment to this conservative approach is being developed by the District through the development of a survey of a representative sample of disaggregated sector characteristics. The results will be incorporated into FAWCET in order to establish reasonable ranges to adjustable assumptions in the tool, including the passive replacement or indoor upgrades of fixtures.

Indoor Upgrades

Nine indoor fixture upgrades are identified as more efficient options: low-flow-volume shower heads, high-efficiency shower heads, low-flow faucets, ultra-low-flush toilets, high-efficiency toilets, high-efficiency clothes washers, high-efficiency dishwashers, ultra-low-flow urinals, and high-efficiency urinals. The tool allows for toggling on and off of fixture replacement options. The option to add new BMPs for replacement is included and can be used if the savings rates and costs, as well as the impact to the correct use proportions, are known, or can be reasonably estimated. The upgrades are defined here.

Low-Flow-Volume Shower Head Replacement

This strategy involves replacing existing shower heads with low-flow-volume models. These shower heads allow less than 2.5 gal per min (gpm) to flow through the head. The shower heads cost $35 to implement, including installation, and have a device life of 15 years. The percentage of existing low-flow-volume shower heads for each building-age category varies by utility and sector makeup.

Houses older than 1984, known as BO1, are likely to have a greater number of low-flow-volume shower heads compared with BO2, the designation for houses built between 1985 and 1993, as there would have been replacements due to bathroom renovations or fixture wear-out. All houses built after 1994 to the present day were estimated to have low-flow-volume shower heads installed because of the change in plumbing codes. It was estimated that the water savings generated from converting a shower head to a low-flow-volume shower head would be 3.9 percent. The FAWCET allows for options among several types of BMPs; in this case, low-flow and high-efficiency showerheads. (Castaneda, 2012).

High-Efficiency Shower Head Replacement

This strategy involves replacing the current shower heads with high-efficiency fixtures, which have a flow rate of less than 1.5 gpm. This type of strategy is relatively inexpensive, with heads costing around $40, including installation. These upgrades have an expected life of around 15 years. The number of available program replacements is unique to each utility's housing stock and the useful life of each BMP (Castaneda, 2012).

Low-Flow Faucet Aerator Replacement

This approach involves replacing kitchen and bathroom faucets with low-flow ones. Kitchen faucets are replaced with 2.20 gpm models, while bathroom faucets would be upgraded to 1 gpm. The savings for these replacement faucets are assumed to be split proportionally between the bathroom and kitchen. Although the total water savings is typically low, this approach is cost-effective (about $15 per fixture upgrade) and can be very competitive due to the energy savings also gained.

Ultra-Low Flush Toilet Replacement

This ultra-low flush BMP replaces the current high-flow toilets with ultra-low models, which use 1.6 gal per flush (gpf). These toilets cost around $300 each to replace and last around 40 years. Current plumbing standards require ultra-low flush toilets to be installed in new buildings. This is another case where FAWCET allows for the consideration of fixture options.

High-Efficiency Toilet Replacement

This approach involves replacing current toilets with those that are high-efficiency. These toilets have a dual-flush system that allows 0.8 gpf for urine and 1.2 gpf otherwise. This system has a total cost of $400 per implementation. It is assumed that all current toilets are either ultra-low-flush or are less efficient models. While the preceding fixtures, including toilets, are considered to be relatively low-cost, there are a few other BMPs, which at first glance, seem to be very costly.

High-Efficiency Clothes Washer Replacement

This strategy requires replacing inefficient washing machines with high-efficiency washers (27 gal per load). The problem with this type of upgrade is that residents may take the washing machine with them when they leave, especially as these represent a high cost to the customer ($850 per machine). If residents take their clothes washers with them, it makes it more difficult to estimate the percentages of buildings that have high-efficiency models. Nevertheless, where water volumes are present in a residential setting, it is assumed that there is a functioning clothes washer and it is using a fairly high proportion of water, compared to a dishwasher.

High-Efficiency Dishwashers

This strategy replaces existing dishwashers with more efficient versions (4.5 gal per load). The water savings are very low compared with the cost of implementation, which at $850, makes this strategy less favorable when energy savings is not a consideration. The percentage of existing high-efficiency dishwashers across all building ages was zero; this was because it was assumed that all dishwasher passive replacements have occurred with 7-gal-per-load models.

High-Efficiency Urinal Replacement Program

The urinal replacement program replaces inefficient urinals with high-efficiency fixtures (0.5 gpf). This approach would cost $450 per installation in CII categories. Passive replacements or existing upgrades for high-efficiency urinals are assumed to be zero. The exact estimation of percentage of water savings varies with each account (Castaneda, 2012). This is another case where a choice between two options is considered.

Waterless Urinal Replacement Program

The waterless urinal program replaces inefficient urinals in CII categories with waterless ones. Waterless urinals require no water supply plumbing or flushing. It is assumed that there have been no existing upgrades of this type of fixture at present and the percentage of water conservation savings varies with each account. The cost of implementation, at $625, is greater than that of high-efficiency urinals (Castaneda, 2012). The water urinal is the last on the list of options for indoor use; however, as mentioned previously, additional options can be added for both indoor and outdoor BMPs. Waterless urinals have been criticized for urea buildup, which can occur with a reactive or deferred maintenance schedule. The FAWCET assumes the proper installation of the units and that proactive maintenance schedules, which include occasional flushing, are in place.

Outdoor Best Management Practices

Outdoor upgrades focus on improving the entire irrigation system, rather than specific fixtures, as with the indoor upgrades. The six different options—operation-based residential irrigation audit, repair-based residential irrigation audit, design-based residential irrigation audit, soil moisture sensors, advanced evapotranspiration (ET) irrigation controllers, and Waterwise Florida Landscape—are described.

Operation-Based Residential Irrigation Audit

This approach identifies the most common and simplest problems linked to residential irrigation systems, which include vegetation blocking the sprinkler stream, water overflowing onto pavement, frequency of use, and length of time irrigation is used on the property. The audits would be required to be conducted frequently over the years to maintain an efficient irrigation system. This approach would cost around $150 for the first year and $75 for subsequent years, assuming the system is in relatively good condition and does not need major repairs.

Repair-Based Residential Irrigation Audit

The objective of this BMP is to identify maintenance problems related to residential irrigation, such as leaks and broken valves, and selecting the correct type of sprinklers for an area. In order to maintain an efficient system, the audits would need to be maintained over several years. The cost of employing this approach is $250 for the first year and $100 for subsequent years. This BMP assumes the system is designed properly.

Design-Based Residential Irrigation Audit

This audit focuses on the design of residential irrigation systems, including the efficient irrigation of the landscape, soil moisture sensors, and fixing poor overlap of sprinklers. To ensure that an efficient system is maintained, the audit is required to be conducted every two years; this results in an initial cost of $500 in the first year and $100 every subsequent year.

Soil Moisture Sensors

This approach requires soil moisture sensors to be installed in residential properties to shut off the irrigation system, depending on the soil moisture. This strategy costs $300 and is only implemented if design- and repair-based audits are in place. It is assumed that there are currently no existing soil moisture sensors in place in residential categories.

	A	B	C
1	Fixture Upgrades	Reference Number	
2	Low Flow Showerhead	1	
3	High Efficiency Showerhead	2	
4	Bathroom Faucet Aerator	3	
5	Kitchen Faucet Aerator	4	
6	Ultra Low Flow Toilet	5	
7	High Efficiency Toilet	6	
8	High Efficiency Dishwasher	7	
9	High Efficiency Clothes Washer	8	
10	Ultra Low Flow Urinals	9	
11	Waterless Urinals	10	
12	Operation Based Irrigation Audit	11	
13	Repair Based Irrigation Audit	12	
14	Design Based Irrigation Audit	13	
15	Soil Moisture Sensors	14	
16	Advanced ET Controllers	15	
17	Waterwise Florida Landscape	16	

Figure 8. Identifiers used to identify each possible fixture upgrade (BMP) *f=1, 2, …, 16* considered by the model. Fixture upgrades 1-10 are upgrades to indoor fixtures, while fixture upgrades 11-16 all address outdoor irrigation systems.

Advanced Evapotranspiration Irrigation Controllers

The advanced ET irrigation controller requires installment of signal-based sensors that automatically control the irrigation system based on the needs of the landscape. This strategy would cost around $400 per implementation. It employs signal technology from a weather-based network or a local or on-premises weather station to provide feedback regarding current conditions to adjust the irrigation system.

Waterwise Florida Landscape

This program requires the replacement of existing landscaping with plants that are more suited to the Florida environment and hydrology. It aims to eliminate water consumption for irrigation by reducing the size of the irrigation system and/or the flow rate by reducing the percentage of turf with mulched beds and a variety of native and non-native plants, stressing Florida's "right plant, right place" concept. This strategy costs around $2,000 and requires a "watering in" period; however, no further watering is required after this stage.

Other Global Best Management Practices

In addition to the BMPs already mentioned, there are several other methods incorporated into the modeling process. Ordinances adopting higher-efficiency standards take the existing federal, state, and local requirements into consideration and ratchets up the standard. The modifications to land development

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regulations accomplishes a similar goal, but restricts its application to the development community, or in some cases, the real estate community. An example of a modification applied to a real estate community would be to require any property changing hands to replace all existing inefficient fixtures with ones with the latest standards of efficiency (Water Star℠ or WaterSense, for example). The costs associated with these types of policy changes are typically administrative and involve the time it takes for administrators working with legal staff, the impacted community, and stakeholders to vet proposed policy changes, finalize language, and communicate the intention to pass the new legislation. The costs per parcel are minute in comparison (about $3 per parcel) and therefore are very competitive.

FAWCET Models

The original model was developed using the OpenSolver (http://OpenSolver.org) optimizer (Mason, 2012), an open-source add-in for Microsoft Excel that allows the user to solve linear and integer programming models with large numbers of decision variables. (The alternative solver add-in bundled with Excel restricts the user to no more than 200 decision variables.) In the original model, the fixture counts and water uses by parcel were combined into groups by DOR code, as well as fixture counts and water use volumes (Castaneda, Blush; 2011). The new model considers each parcel individually and results in many more decision variables to be processed. When using the new account-by-account model, the OpenSolver model formulation took too long to solve the optimization model. To remedy this, the model was redeveloped using the Python-based modelling language PuLP (Mitchell et al, 2011) and embedded in Excel using the SolverStudio (http://solverstudio.org), which is a free Excel add-in that makes optimization modelling languages such as PuLP available in a spreadsheet (Mason, 2012). Moving to SolverStudio allowed the time required to solve the optimization models to be significantly reduced.

The SolverStudio version of FAWCET contains three separate tabs: the first tab defines the assumptions made such as the budget available; the second includes the linear program; and the third summarizes the results of the optimization. An additional tab is used for determining the passive replacement rates and assumes conservatively that all fixtures that have reached the end of their useful lives according to the manufacturer have been replaced.

Formal Definition of the Optimization Model

Given n parcels and m types of fixture upgrades that can be performed at each parcel, the optimization model determines for each parcel p, $p=1, 2, \ldots, n$, the number $x_{p,f}$ of fixture upgrades of type f that should be made at parcel p to maximize the total water savings across the District while satisfying a budget requirement. This maximization is also constrained by the number of fixtures of each type available for upgrading at each parcel. The equations used to define the model use the numbering of the m=16 types of fixture upgrades are given in Figure 8.

Objective Function

The objective of the linear program (equation 1) aims to maximize the sum of the savings made over the fixture upgrades made at the parcels. Each parcel represents all the information for an account.

$$\max \sum_{p=1}^{n} \sum_{f=1}^{m} s_{p,f} x_{p,f} \qquad (1)$$

The objective of the linear program (equation 1) is to maximize the sum of the savings obtained from the number of upgrades of each fixture for each parcel, $s_{p,f}$ where the savings are generated by upgrading one fixture of type f at parcel p, and $x_{p,f}$ is the integer number of such upgrades to be made. This objective function is maximized subject to the savings, cost, and fixture constraints described.

Constraints

The first constraint ensures that the total amount spent on upgrades is within some budget limit c_{max}, where each fixture upgrade of type f at parcel p costs $c_{p,f}$:

$$\sum_{p=1}^{n} \sum_{f=1}^{m} c_{p,f} x_{p,f} \leq C_{max} \qquad (2)$$

The savings constraint described (equation 2) ensures that the total water savings are greater than the minimum water conservation requirements for the District. Equation 2 is redundant since the objective is to maximize the water savings, and therefore, will satisfy this constraint; however, both the OpenSolver and SolverStudio versions of FAWCET have the minimum savings constraint. While the cost constraint (equation 3) ensures that the total cost of implementing the optimum strategy is within the utility's budget, it is important to note that if the utility does not allocate enough money to its water conservation budget, the problem will become infeasible. To solve the infeasibility problem, the District would have to increase the amount of money dedicated to this project.

The model also includes 'indoor' and 'outdoor' constraints that ensure the total number of upgrades made at parcel p of a particular class of fixtures does not exceed the number of such fixtures available to be upgraded at that parcel (see Figure 8).

Indoor Constraints

$x_{p,1} + x_{p,2} \leq n_p^{shower}$ for $p = 1,2,\ldots,n$ (3)

$x_{p,1} + x_{p,2} \leq n_p^{bathroom}$ for $p = 1,2,\ldots,n$ (4)

$x_{p,1} + x_{p,2} \leq n_p^{kitchen}$ for $p = 1,2,\ldots,n$ (6)

$x_{p,1} + x_{p,2} \leq n_p^{toilet}$ for $p = 1,2,\ldots,n$ (7)

$x_{p,1} + x_{p,2} \leq n_p^{dishwasher}$ for $p = 1,2,\ldots,n$ (8)

$x_{p,1} + x_{p,2} \leq n_p^{clotheswasher}$ for $p = 1,2,\ldots,n$ (9)

$x_{p,9} + x_{p,10} \leq n_p^{urinal}$ for $p = 1,2,\ldots,n$ (10)

Outdoor Constraints

$x_{p,11} + x_{p,12} + x_{p,13} + x_{p,14} + x_{p,15} + x_{p,16} \leq n_p^{irrigation}$ for $p = 1,2,\ldots,n$ (11)

where the model relies on the following values having been defined as:

- n_p^{shower} the number of available shower heads at parcel p,
- $n_p^{bathroom}$ the number of available bathroom faucets at parcel p,
- $n_p^{kitchen}$ the number of available kitchen faucets at parcel p,
- n_p^{toilet} the number of available toilets at parcel p,
- $n_p^{dishwasher}$ the number of available dishwashers at parcel p,
- $n_p^{clotheswasher}$ the number of available clothes washers at parcel p,
- n_p^{urinal} the number of available urinals at parcel p, and
- $n_p^{irrigation}$ the number of available irrigation systems at parcel p.

Non-Negative Integrality Constraint

$x_{p,f} \geq 0$, integer for $p = 1,2,...,n$, $f = 1,2,...,m$ (12)

The indoor constraints (3) to (10) ensure that the number of upgrades made to fixtures at a parcel do not exceed the number of fixtures available at that parcel, where the fixture types are defined in Figure 8. The outdoor constraint ensures that the right types of upgrades are allocated to each parcel. The final non-negativity constraints ensure that all the decision variables are a positive integer (or zero) in the final solution. The final values ($x_{p1}, x_{p2}, \ldots, x_{p16}$) specify the optimized number of upgrades made at a particular site can be either one type of audit strategy or a combination.

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Alternative Formulation

The model as presented maximizes the water savings achieved for a given budgeted expenditure C_{max}. In some cases, however, the user may wish to determine what expenditure is required to achieve some specified water savings target S_{min}. In this case the objective (1) and constraint (2) are changed to become:

$$\min \sum_{p=1}^{n} \sum_{f=1}^{m} c_{p,f} x_{p,f} \quad (1')$$

$$\sum_{p=1}^{n} \sum_{f=1}^{m} c_{p,f} x_{p,f} \geq S_{min} \quad (2')$$

Potential Water Savings

The model needs values for the savings *sp,f* that will be generated by each fixture upgrade (or outside intervention) made at parcel *p*. The potential water savings for an account are proportioned into water savings per fixture upgrade.

Indoor Water Savings per Fixture Upgrade

$$s_{p,f} = \frac{E_{p,f} - U_f}{E_{p,f}} \times \frac{V_{p,f}}{n_p^f} \quad (3)$$

The indoor water savings per fixture upgrade $s_{p,f}$ for parcel *p* are calculated using equation 3. The fraction of water saved by upgrading one such fixture is given by $E_{p,f}$ - $U_f/E_{p,f}$, where $E_{p,f}$ is the existing water usage of fixtures of type *f* at parcel *p* (which depends on the estimated age of those fixtures at parcel *p*), and is postupgrade water usage volume of a new such upgraded fixture. Multiplying by the estimated volume of water $v_{p,f}$ used by all such fixtures at parcel *p*, and dividing by the number n_p^f of such fixtures at parcel *p*, gives the final savings value $s_{p,f}$ per fixture upgrade *f* at parcel *p*.

Outdoor Water Savings per Fixture Upgrade

The outdoor upgrade options available for parcels that irrigate depend on whether the parcel is classified as a 'hose irrigator' (if their estimated outdoor water usage is 10,000 gal or less) or an 'inground irrigator' (otherwise) in equation 4. The only upgrade possible for a hose irrigator parcel *p* is to implement Water-Wise Florida Landscape, and so the savings $s_{p,f}$ from the other outdoor upgrade options are all zero, i.e., $s_{p,f} = 0$ for all $f = 11,12,\ldots,15$ for such parcels *p*. Inground irrigators have the full range of upgrade options available. The savings associated with these possible outdoor upgrades are given by

$$s_{p,f} = \frac{V_p^{\text{outdoors}} \times I_{p,f}}{n_p^{\text{irrigation}}} \quad (4)$$

where v_p^{outdoors} is the estimated volume of water used for irrigation at parcel *p*,$I_{p,f}$, is the percentage improvement expected by performing outdoor upgrade *f* given the current state at parcel *p*, and, as before, $n_p^{\text{irrigation}}$ is the number of irrigation systems available for upgrade at parcel *p*.

Cost of Implementation Over the Period

The model can consider costs over some specified time horizon *T*, e.g., *T*=20 years. Some fixture upgrades have expected lifetimes that are longer or shorter than this planning time horizon, and so a correction needs to be made to allow for ongoing replacement of fixtures, equation 5. Thus, for fixtures the model uses costs $c_{p,f}$ given by:

$$c_{p,f} = c_{p,f}^{\text{initial}} \times \frac{T}{t_f} \quad (5)$$

where $c_{p,f}^{\text{initial}}$ is the initial purchase and installation cost of a fixture upgrade *f* at parcel *p*, *T* is the length of the planning time horizon, and t_f is the expected lifetime of an upgraded fixture f. The total costs of implementing outdoor BMPs used by the model are computed using the detailed costs given earlier.

FAWCET Assumptions Tab

The assumptions tab contains all the assumption information that is needed for the linear program to be executed. A distinguishing feature of FAWCET is the ability to adjust any or all assumptions in the tool. All of the following assumption descriptions can be adjusted to allow for professional judgment from experienced water conservation professionals or planners in goal setting, scenario playing, or sensitivity analysis of the tool. It allows for consideration of each utility's uniqueness in residential housing stock, as well as a wide variety of water-using sectors, and therefore, provides for an individual utility's unique water conserving potential. The assumptions 2B-8B in Figure 9 allow users to insert their desired value:

- Conservation Program Start Year
- Maximum Capital Cost (Budget)
- Minimum Savings (gpd)
- Implementation Period (Planning Horizon)
- Saturation Goal
- Discount Rate (Amortization Rate)

Boxes 8B-10B in Figure 9 are drop-down boxes that allow several options. The 8B box allows the user to run the optimization from several different perspectives:

- Total Cost
- Utility Cost
- Customer Cost
- Water Management District (WMD) Cost
- Other Funding Source Cost (e.g., energy company)

The 9B box allows the user to include or exclude "yes or no" savings associated with the

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	A	B
1	Linear Program Global Assumptions	
2	Conservation Program Start Year	2013
3	Maximum Capital Cost ($)	$2,000
4	Minimum Savings (Gallons per Day)	1
5	Implementation Period	20
6	Saturation Goal	75%
7	Discount Rate	4%
8	Cost Perspective	Utility Cost
9	Include Revenue Impact from Water & Wastewater Bills	Yes
10	Payback Period Cap (Years)	10

Figure 9. Linear programs global assumptions allow for a range of objective functions, subject to a range of constraints (not shown).

Existing Fixture Efficiency							
	Showerhead	Bathroom Faucet	Kitchen Faucet	Toilet	Dishwasher	Clothes Washer	Urinal
1	6	4	5	5	7	51	3
2	3	3	4	3.5	7	43	1.8
3	2.5	2.5	3.5	1.6	7	39	1
4	2.5	2.5	3.5	1.6	7	39	1

Figure 10. An estimate of the number of gal per minute/flush/load used by these fixtures across each building plumbing code category, depending on the date of construction for the building (see Figure 7).

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revenue impact from water and wastewater bills (see "Reported Information").

The 10B box allows the user to select 1-20, which is the payback period year the user would like the result limited to. Currently, the federal government requires all buildings to invest in water conserving projects that have a payback period of less than 10 years.

These assumptions, and the assumptions that follow, are used by the linear program tab to further define the global constraints for the optimization, beginning with maximum savings at a given capital cost or budget. The value of these constraints is not fixed, as they may be dependent on such factors as the funding available.

Existing Fixture Efficiency

Another important table in the assumption tab specifies the estimated existing efficiencies of indoor fixtures. The existing baseline efficiencies for showerheads, bathroom faucets, kitchen faucets, and so on, are included in Figure 10.

The estimated efficiencies for toilets and urinals are determined in gal per flush, while dishwasher and clothes washer efficiencies are defined in gal per load. These existing efficiencies are important as they are used in the linear program tab to calculate the potential water savings for a particular indoor fixture upgrade.

The fixture count in the assumptions page is used to estimate the number of showers, bathroom sinks, toilets, and urinals per sq ft of building based on historical building standards (Jones Edmunds, 2010). The linear program uses this information to determine the number of fixtures per building. The number of fixtures is required to determine the potential water savings for each fixture in an account.

Information about the replacement fixtures is also stored in the assumptions page (see Figure 12). The replacement fixtures require information about their potential water savings, total costs for implementing a fixture upgrade, life of the device, and water savings efficiencies for the fixtures.

The fixture ratings describe the water savings that can be produced by implementing these fixture upgrades. Outdoor-fixture water savings are described as a percentage of outdoor water use volume that can be saved by implementing these strategies, while indoor-fixture ratings describe the number of gal per unit that can be saved indoors by implementing these changes. The fixture ratings are used to calculate the potential water saving for each fixture in the linear program tab.

The total costs are the costs of implementing a fixture upgrade, including the retail cost of the BMP and installation. The linear program calculates the total cost of implementing all upgrades that are identified by the optimization. Costs can be adjusted to reflect economies of scale or discounted purchases of equipment.

Fixture Counts							
Customer Category	Showers	Bathroom Sinks	Kitchen Sink	Toilets	Dishwasher	Clothes Washer	Urinals
Single Family	0.0009	0.0009	1	0.0009	1	1	0
Multi Family	2	2	1	2	1	1	0
Hospitals	0.000177229	0.0012406	0	0.0012406	0	0	0.0006203
Hotels	0.002173913	0.002173913	0	0.002173913	0	0	0
Indoor Recreation	1	2	1	4	0	0	1
Live-In Care	0.001041667	0.001666667	1	0.001666667	0	0	0.000833333
Office Buildings	0	0.0004	0	0.0004	0	0	0.0002
Restaurants	1	2	1	4	0	0	1
Retail	0	0.000133333	1	0.000133333	0	0	0.000066667
Schools	0	0.0008	1	0.0008	0	0	0.0004

Figure 11. Construction standard multipliers are applied to sq ft of a heated area by parcel to determine the number of fixtures in each residential or commercial building. The goal is not to capture the exact number of fixtures, but to determine a number of inefficient fixtures that could be reasonably considered for replacement in a water conservation program.

Replacement Fixtures						
Fixture Type	BMP Active	Fixture Rating or Savings %	Total BMP Cost	Device Life (Years)	Water Savings Effectiveness	Percent Hot Water
Soil Moisture Sensor	Yes	25%	$300	10	100%	0%
Advanced ET Controller	Yes	25%	$400	10	100%	0%
Operation Based Irrigation Audit	Yes	25%	$150	2	95%	0%
Repair Based Irrigation Audit	Yes	40%	$250	2	95%	0%
Design Based Irrigation Audit	Yes	60%	$500	2	95%	0%
Net Irrigation Requirement Based Audit	Yes	40%	$250	2	95%	0%
Waterwise Florida Landscape	Yes	85%	$2,000	20	100%	0%
Low Flow Showerhead	Yes	2.5	$35	15	90%	75%
High Efficiency Showerhead	Yes	1.5	$40	15	90%	75%
Bathroom Faucet Aerator	Yes	1	$15	10	90%	70%
Kitchen Faucet Aerator	Yes	2.2	$15	10	90%	70%
Ultra Low Flow Toilet	Yes	1.6	$300	40	100%	0%
High Efficiency Toilet	Yes	1.2	$400	40	100%	0%
Dishwasher	Yes	4.5	$850	13	100%	100%
Clothes Washer	Yes	27	$850	13	85%	40%
Low Flow Urinals	Yes	0.5	$450	40	100%	0%
Waterless Urinals	Yes	0	$625	40	100%	0%
Indoor Efficiency Ordinance	Yes	5%	$3,000	20	100%	0%

Figure 12. The replacement fixtures shown allow the user to activate and deactivate BMPs; details of each BMP are included. The total BMP cost, flow rate, device life, and percentage of hot water are important factors when determining the total costs and benefits of a BMP.

Reported Information

The bottom section of the assumptions tab includes additional information that can be reported as part of the result of the optimization. Any of this reported information can also be used as an objective function or a constraint. The variable rate information is used to calculate the bill before and after fixture replacement. The residential customer electric rate is used to calculate the energy savings and utilizes the fixture flow rate and percentage of hot water to report the resulting savings. Utility electric consumption includes the electricity used in production and treatment, distribution of water, and collection of wastewater for the utility. Additional utility operating expenses estimate savings from chemicals and energy costs. Most of these data points are provided by the utility being examined (see Figure 13).

The percentage of hot water saved by an indoor fixture is used on the linear program page to determine the amount of energy saved by switching to more efficient fixtures. The calculated energy savings is used to estimate the reduction in the energy bill by implementing the suggested fixture changes. Explaining the monetary savings gained by switching to more efficient fixtures is a pivotal way to plan and implement water conservation programs. District staff has taken the approach of focusing on FAWCET for every other reason except water conservation. Using an exhaustive approach of capturing every conceivable cost and benefit to customers, utilities, and management districts from the adoption of best management practices ensures that water conservation efforts are being planned and implemented on the basis of reasonable business decisions with lasting impacts to the resource. There are many examples of this being the case in large-scale water-conservation-related projects in Florida. There are many more examples of this approach in the energy industry across the United States.

Linear Program Page SolverStudio PuLP Model

The SolverStudio model was developed using the modeling language PuLP. Data in comma-separated values (CSV) format housed in a user-specified location through a file path is processed in the SolverStudio optimization. This was achieved by using the SolverStudio data editor, which allows cell ranges and indexes to be identified for important information that can be used in the PuLP model (see Figure 14). The values required for the model are the costs, savings, reported benefits and costs, cost of each implementation, and the available fixtures for upgrade.

The PuLP model is defined in the dialog box (see Figure 15), which was created in the linear program tab. The model requires the file path where the CSV-formatted data resides, and then requires a file path to identify where the output file will be written. This means that the actual data is housed in an area separate from the spreadsheet and allows for faster solve times and processing of millions of accounts. This is an important improvement to FAWCET and can be clearly understood by anyone who has dealt with very large Excel databases. Opening an Excel database with this many accounts, complete with complex lengthy calculations, will cause memory or performance errors in most machines. Excel tries to execute calculations automatically upon opening of the workbook. Disabling the calculations would not be of any benefit, since the spreadsheet will eventually perform the calculations; when the data is housed separately from FAWCET, this problem is eliminated.

	Variable Rate Within City/County Limits	
User Class & Sub-class	**($/Kgal)**	**($/gal)**
SF - No Irrigation Meter	$1.98	$0.00198
SF - with Irrigation Meter	$1.98	$0.00198
Duplexes - Individually Metered Units; without Irrigation Meter	$1.98	$0.00198
Duplexes - Individually Metered Units; plus Irrigation Meter	$1.98	$0.00198
Duplexes - Not Individually Metered without Irrigation Meter	$1.98	$0.00198
Duplexes - Not individually Metered plus Irrigation Meter	$1.98	$0.00198
MF - Not Individually Metered (with or without Irrigation Meter)	$1.98	$0.00198
MF - Individually Metered without Irrigation Meter	$1.98	$0.00198
MF - Individually Metered; plus Irrigation Meter	$1.98	$0.00198
NR (with or without Irrigation Meter)	$1.98	$0.00198
Oil & Grease		
Industrial Pre-treatment		

SF = single family residence
MF = duplexes, condos, town homes, and mobile home parks
Unit = SF residence, a duplex, a mobile home, or an apartment/condo unit
NR = non-residential
*Note that for a Duplex that is not individually metered, the "unit" refers to the entire duplex (per Mt. Dora rates)

Residential Customer Electric Rate ($/kWh)	$0.038740
Conversion Factor Gallons to kWh	0.18
Utility Electric Rate ($/kWh)	$0.038740

Utility Electric Consumption	kWh/gal
Water Treatment	0.00165
Water Distribution	0.00059
Wastewater Treatment	0.00162
Wastewater Collection	0.00008
*Waiting to hear back from Mount Dora on their variable costs	

	Utility Operating Costs	
Operating Expense	**$/Kgal**	**$/gal**
Water Treatment Chemicals	$0.10	$0.00010
Water Energy Costs	$0.20	$0.00020
WW Treatment Chemicals	$0.12	$0.00012
WW Energy Costs	$0.15	$0.00015

Utility Water Loss from WTP to Customer's Meter (as a percent of water produced)	10%

Figure 13. Additional information regarding utility customer variable rates and energy and treatment costs at the water and wastewater treatment plants; similar information is used to capture as many possible benefits of conservation as possible. Since each of these costs or benefits can be determined by parcel, all reported information can also be used as an objective function or constrain the objective function, or both.

When the model is solved, the optimal water savings and the time it took to solve the model are displayed in the model output box (see bottom of Figure 15). The fixture upgrades for each account that were identified in the optimization are simultaneously written in the folder identified by the file path provided (see Figure 16). The file path for the output file does not have to be generated into the same folder as the data input file. A separate file path, perhaps one typically used for generating geodatabases in ArcGIS or ArcGIS Online, can be provided.

The linear program page (see Figure 17) contains the objective function, which utilizes the assumptions tab and CSV data to maximize the total water savings across the District, while staying within a given budget. The linear program gets information about the budget and minimum water savings from the assumptions tab.

The water conservation linear program is constrained by the maximum number of fixtures that can be upgraded for each residential or CII account. The optimization requires the program to calculate the number of fixtures for each account, the water savings, and the cost of an upgrade for each end use. Water savings and costs are first calculated for each individual end use and then combined to determine the total savings and cost of each implementation. When the optimization is run, it identifies the number of fixtures that need to be upgraded for each account. This is then written as the output file and aggregated and displayed in the summary tab.

Summary Tab

The summary tab is the "punchline" of the entire process. It displays the number of passive replacements over the desired planning horizon and the fixture upgrades that were identified during the optimization. Figure 18 shows an example of the summary page for an optimization of 100 accounts and a budget of

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$20,000. The summary page, when combined with the output file, allows for the development of a phased approach to implementing the water conservation plan. One approach is to develop the logistical plan, using a geodatabase generated from the output file. Implementation begins by order of cost. The BMPs, beginning with the least expensive strategies, are targeted first in the early years of the plan, saving the more costly BMPs for the later years. This approach would allow for changes in costs or benefits to occur during the plan implementation schedule and allow for the continued improvement of the plan to take advantage of price differences through time. There are many changes taking place in the industry that could be leveraged through iterative approach planning. The FAWCET processing times are extremely fast and FAWCET was developed with a continuous improvement process in mind.

Passive Replacement

The passive replacement (existing upgrades) of fixtures is estimated by applying useful lives of individual devices in the existing fixtures tab to the number of available fixtures beginning in the year the building was constructed and at the end of each fixture's useful life (see Figure 19). This process continues to be impacted by the federal plumbing code

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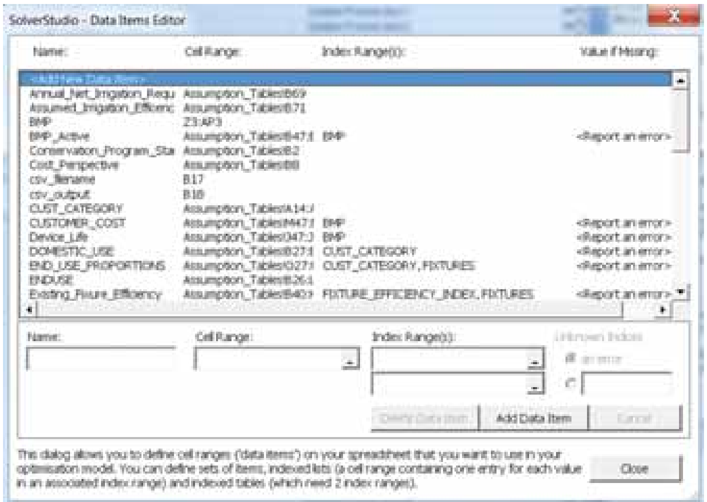

Figure 14. (Above) The data editor allows cell ranges and indexes to be identified for executing the PuLP model.

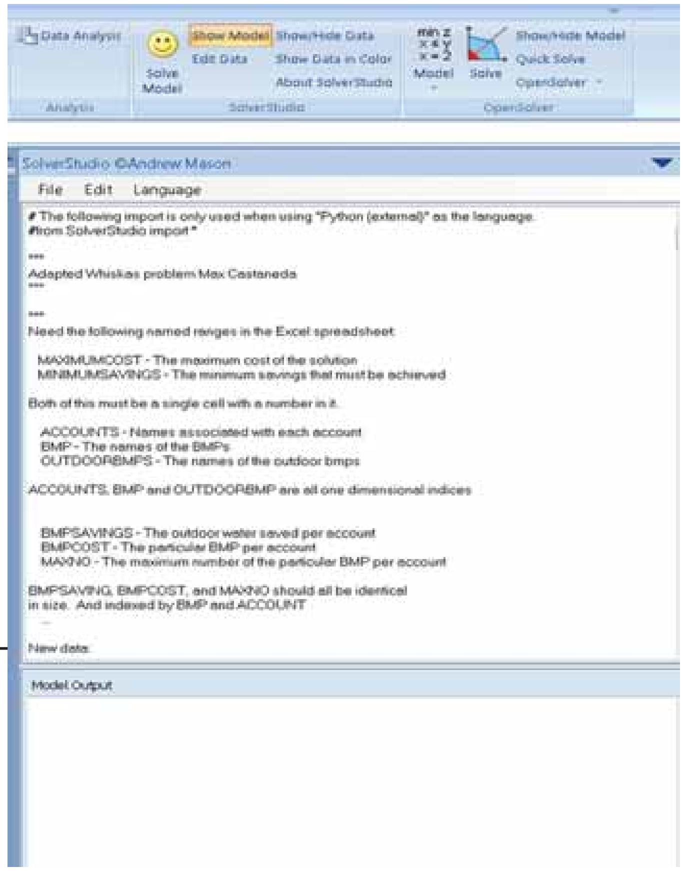

Figure 15.,(At right) The PuLP model is defined in the dialog box, which was created on the linear program page. The output process stages save time and results are displayed in the model output window, while the output is generated in the location designated by the file path provided.

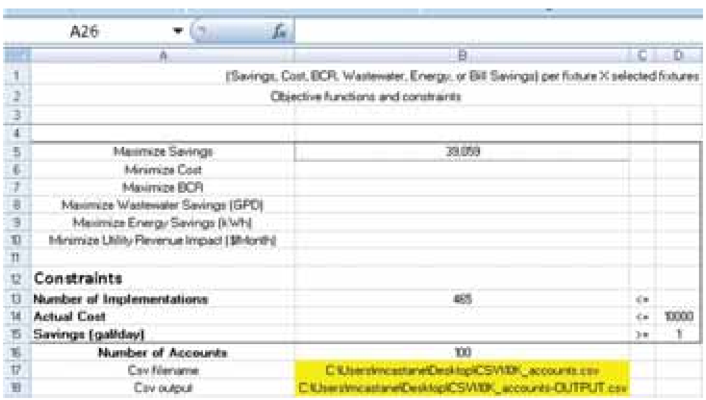

Figure 16. The user-provided file path is used by FAWCET to find and process the input file. The FAWCET uses the file path provided to store the output file showing the parcels that were selected by the model.

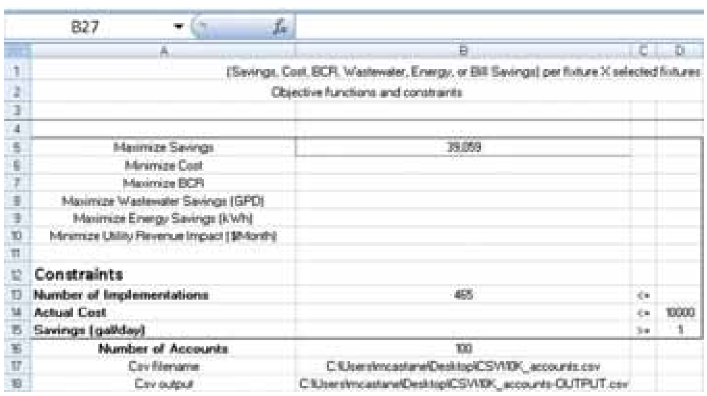

Figure 17. The linear program page includes the global objective function options from the assumptions tab, and constraints. The file path needed to identify the location of the input and final destination of the output file is also shown.

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standard, today's date, the planning horizon, the plan start date, and so on. The method of calculating passive replacement is conservative in that it assumes all fixtures are being replaced at the end of their useful lives. It credits utilities and their customers for replacing, like clockwork, inefficient fixtures with more efficient fixtures. It assumes customers feel some pressure in their pocketbook to replace fixtures due to increasing block rate programs and their own ecological awareness. Even with this conservative assumption in place, the potential for water conservation calculated by the tool can reach a 20-percent-and-above decrease in water demand for most locations. This is likely due to the fact that the current plumbing standard has not kept pace with the efficiencies reached by the latest BMPs.

Small Example Model Runs

The FAWCET assumptions located in the assumptions tab are all completely adjustable. For the purpose of demonstrating easy-to-understand outputs from FAWCET, a sample of 100 actual utility accounts was run. The adjustable assumptions (see Figure 20) begin with the total budget and end with the sub-bullet points under the BMP device life and install costs heading. A series of reported information developed from tables is included in FAWCET on the assumptions page. In Figure 20, those reported amounts begin with a BMP percentage of hot water use and end with the sub-bullets under utility operating costs. This information, with a reported output for the 100-account test runs, can be used as objective functions or constraints in the tool. One simple example would be optimizing for maximum energy savings, while delivering only those residential accounts with a BCR over 10 or gpcd under 70, or schools with a BCR over 30.

If FAWCET were to include average annual income by parcel from the census or a cost of a basket of goods calculated from the census information, it could maximize water savings and deliver only those parcels with a savings of 5 percent of their average annual income, or a percentage savings of a customer's household basket of goods at 10 percent. Any piece of information that can be reasonably or accurately estimated on a per-household level, and placed within the row of individual parcels in FAWCET as an element of data for that parcel, can be used as an objective and/or a constraint in the problem. As an extreme example, if one were to include the color of the home, one could return the maximum energy saved up to a maximum of $30,000 constrained to only those homes that are blue.

For the small-model example runs, 100 single-family accounts were used; a total budget constraint of $2,000 was used as a utility budget. Both model runs were based on the utility cost perspective. The two objective functions were to maximize water and energy savings. The FAWCET took 15 seconds to run each optimization. Each run includes a load profile for the 100 accounts (see Figures 21 and 22). The targeted account volumes are shown in each load profile, indoor (upper) and outdoor (lower) in Figures 21 and 22, top left. The "maximize water savings" objective function targets high-using indoor accounts and high-using outdoor accounts. The FAWCET recommends a large number of kitchen faucet aerators, repair-based irrigation audits, and a few design-based irrigation audits. The gpcd is reduced from 149 to 125. A 4-gal reduction in gpcd is due to indoor replacements, while a 20-gpcd reduction is due

Utility Summary					
Conservation Program Variables					
Discount Rate	4%		Residential Per Capita		
Program Implementation Period	20		Before Conservation		After Conservation
Capital Cost Threshold	$20,000		149		148

Residential Conservation Practice	Historical Passive Savings (gpd)	Future Passive Savings (gpd)	Number of Program Implementation	Cost per Program Implementation	Program Savings (gpm)
Soil Moisture Sensors	0	0	0	$100	0
Advanced ET Irrigation Controllers	0	0	3	$150	3,000
Operation Based Residential Irrigation Audit	0	0	1	$75	238
Repair Based Residential Irrigation Audit	0	0	1	$50	1,900
Design Based Residential Irrigation Audit	0	0	3	$175	0
Net Irrigation Requirement Based Irrigation Audit	0	0	0	$50	0
Water-wise Florida Landscape- Inground	0	0	0	$750	0
LF Showerhead	0	0	0	$10	0
HE Showerhead			0	$13	0
Low Flow Bathroom Faucet Aerators	1,218	0	3	$3	933
Low Flow Kitchen Faucet Aerators	1,705	0	0	$3	0
Ultra Low Flow Toilets	971	388	0	$100	0
High Efficiency Toilets			0	$150	0
High Efficiency Dishwashers	0	0	1	$250	25
High Efficiency Clothes Washers	6,563	0	11	$350	2,327
Ordinances Adopting Higher Indoor Efficiency S	0	0	0	$3,000	0
Modifications to Land Development Regulations	0	0	0	$2.90	0
Subtotals	10,456	388	23		8,422

Commercial Conservation Practice	Historical Passive Savings (gpd)	Future Passive Savings (gpd)	Number of Program Implementation	Cost per Program Implementation	Program Savings (gpm)
LF Shower heads	0	0	0	$10	0
HE Shower heads			0	$13	0
Low Flow Bathroom Faucet Aerators	1,178	0	0	$3	0
Low Flow Kitchen Faucet Aerators	1,649	0	0	$3	0
Ultra Low Flow Toilets	939	0	0	$100	0
High Efficiency Toilets			0	$150	0
Low Flow Urinals	0	0	0	$175	0
Waterless Urinals			0	$275	0
Ordinances Adopting Higher Indoor Efficiency S	0	0	0	$3,000	0
Subtotals	3,765	0	0		0

Summary	Historical Passive Savings (gpd)	Future Passive Savings (gpd)	Number of Program Implementation		Program Savings (gpm)
Total Savings and Program Cost	14,221	388	23		8,422
Total Savings and Program Cost with 20% contin	14,221	388	23		8,422

*Parcel growth based projection is the estimated water use on the customer side of the meter only for the top water using residential and commercial Department of revenue land use categories and does not include plant or delivery system loss.
**Energy savings calculated as avoided utility water treatment and pumping costs due to conservation over the implementation period from Watergy: A Water and Energy Conservation Model for Federal Facilities, 1996. Updated avg electricity cost of $.[illegible]
***Unit cost adjusted for additional savings from avoided utility water treatment and pumping costs due to conservation

Figure 18. All of the information from the FAWCET output file, beginning with passive replacement and program replacements, and the costs and benefits associated with new BMPs.

Original Fixture Efficiency							
Year Bui	Shower	Bathroom Fauce	Kitchen Faucet	Toilet	Urinal	Dishwashe	Clothes Washer
1800	1	1	1	1	1	1	1
1801	1	1	1	1	1	1	1
1802	1	1	1	1	1	1	1
1803	1	1	1	1	1	1	1
1804	1	1	1	1	1	1	1
1805	1	1	1	1	1	1	1
1806	1	1	1	1	1	1	1
1807	1	1	1	1	1	1	1
1808	1	1	1	1	1	1	1
1809	1	1	1	1	1	1	1
1810	1	1	1	1	1	1	1

Existing Fixture Efficiency							
Year Bui	Shower	Bathroom Fauce	Kitchen Faucet	Toilet	Urinal	Dishwashe	Clothes Washer
1800	3	3	3	3	3	3	3
1801	3	3	3	3	3	3	3
1802	3	3	3	3	3	3	3
1803	3	3	3	3	3	3	3
1804	3	3	3	3	3	3	3
1805	3	3	3	3	3	3	3
1806	3	3	3	3	3	3	3
1807	3	3	3	3	3	3	3
1808	3	3	3	3	3	3	3
1809	3	3	3	3	3	3	3
1810	3	3	3	3	3	3	3

Future Passive Replacement Fixture Efficiency							
Year Bui	Shower	Bathroom Fauce	Kitchen Faucet	Toilet	Urinal	Dishwashe	Clothes Washer
1800	3	3	3	3	3	3	3
1801	3	3	3	3	3	3	3
1802	3	3	3	3	3	3	3
1803	3	3	3	3	3	3	3
1804	3	3	3	3	3	3	3
1805	3	3	3	3	3	3	3
1806	3	3	3	3	3	3	3
1807	3	3	3	3	3	3	3
1808	3	3	3	3	3	3	3
1809	3	3	3	3	3	3	3
1810	3	3	3	3	3	3	3

Figure 19. The passive replacement tab assumes customers are replacing fixtures at the end of their useful lives, beginning from when the building was first constructed to the present.

Figure 20. A listing of FAWCETS adjustable assumptions, from total budget to BMP device and install costs, and a listing of reported information from BMP percentage of hot water use to utility operating costs. All of this information, including the reported information, can be used as objectives in FAWCET or used to constrain the tool to deliver a selected range of sectors or selected values.

to outdoor repairs. Total program savings equals 4,758 gpd and the total BCR is 13. A value of 1 represents a break-even point. The total energy savings is 1,640 kilowatt-hours (kWh).

A similar run was performed with the same 100 accounts (see Figure 22). The objective function was then set to maximize energy savings, rather than water savings. This run targets many more indoor accounts, in an attempt to capture the energy used indoors by the customer, and utility energy use as well, from water and wastewater treatment delivery and transfer. The run captures high-using outdoor accounts to capture energy used to treat and distribute drinking water for irrigation. The BMP selections are similar to the maximize-water-savings run. The FAWCET chooses bathroom and kitchen faucet aerators, as well as repair-based and design-based irrigation system audits. The decrease in gpcd is from 149 to 128. The biggest difference is in the BCR. The maximize energy savings objective delivers a BCR of 35, rather than the 13 reflected in the water savings objective. The high BCR reflects the high cost of energy in the treatment and delivery of water, as well as a high percentage of hot water use per fixture within the home. The total program savings is reduced to 4,276 gpd and the kWhs saved is 1,727.

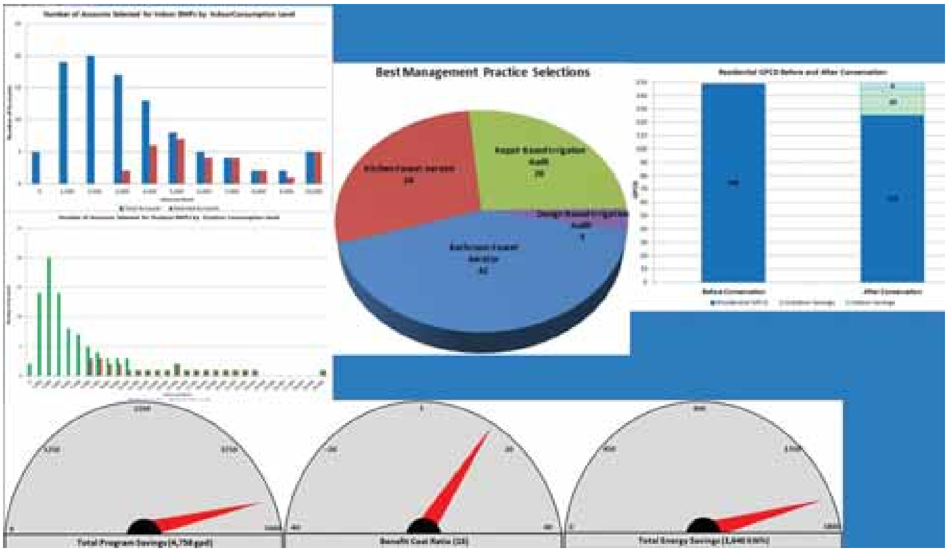

Figure 21. The accounts targeted within the 100-account load profile, with an objective function of maximizing water savings. Also shown are the types of BMPs selected; a variety of reported data, before and after gpcd; total program savings; BCR; and total energy savings.

Water Conservation Potential in the District 2013 Water Supply Plan

The FAWCET is currently being used mainly to estimate the water conservation potential in the District's 18 counties. The FAW-

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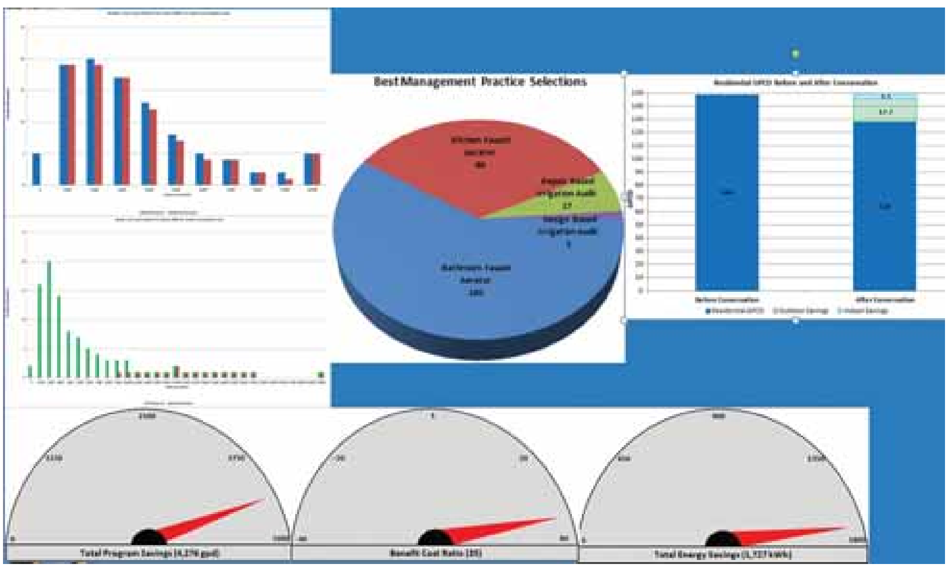

Figure 22. The accounts targeted within the 100-account load profile, with an objective function of maximizing energy savings. Also shown are the types of BMPs selected, a variety of reported data, gpcd, total program savings, BCR, and total energy savings.

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CET is expected to process variations of estimates by utility service area, county, or groundwater basin to generate the water conservation portion of minimum flow level (MFL) prevention and recovery strategies. Individual estimates by utility have been limited thus far to the consumptive use permitting process to share preliminary results with the District's utility partners, demonstrate water conservation potential to regulated utilities, or compare results with estimates developed by utility contractors. An earlier version of FAWCET was run for the District's 2013 water supply plan.

Region	Low Conservation Estimate				High Conservation Estimate			
	Total Conservation Savings	Percent Savings	Total Cost	Cost per Kgal	Total Conservation Savings	Percent Savings	Total Cost	Cost per Kgal
1	20,718,925	6.10%	$36,689,565	$1.28	72,928,927	21.46%	$205,398,174	$0.79
2	8,330,936	6.82%	$30,588,787	$2.45	23,960,071	19.61%	$95,274,849	$1.20
3	*Conserve Florida CFWI Analysis Results*				*Conserve Florida CFWI Analysis Results*			
4	3,587,768	5.87%	$10,805,751	$2.56	9,605,794	15.72%	$55,909,197	$1.61

BMPs used in calculating low estimate:

- Toilets
- Showerheads
- Faucets
- Soil moisture sensors
- Irrigation audits
- Urinals
- Pre-rinse spray valves
- Site-Specific CII Audits

Additional BMPs used in calculating high estimate:

- Ordinances adopting higher indoor efficiency standards
- Modifications to land development regulations
- Water-wise Florida Landscape
- Advanced ET Irrigation Controllers
- Design based residential irrigation audit
- Repair based residential irrigation audit
- High efficiency dishwashers
- High efficiency clothes washers

Figure 23. The results of a previous version of FAWCET, which aggregates customers by sector and volume. The underlying result for this generalized table is the summary tab in FAWCET , which compiles the number of accounts targeted for BMPs by sector and provides the use level to target for implementation.

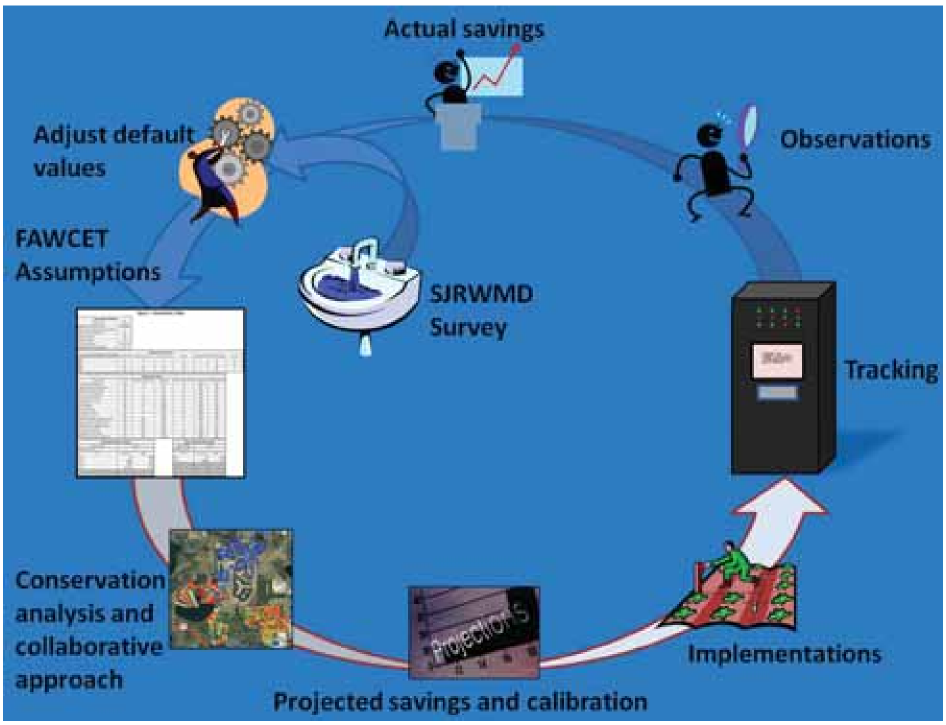

Figure 24. The continuous improvement process for developing a FAWCET-generated goal-based water conservation plan. The process begins with surveys and adjustment of default values, continuing counter-clockwise to actual savings.

The District is divided into four planning regions. A low water conservation estimate was produced using a limited number of BMPs. Toilets, showerheads, and faucet aerators impact residential and CII sectors, while soil moisture sensors and irrigation audits target residential outdoor use. Urinals, pre-rinse spray valves, and site-specific audits target a broad range of CII sectors, or in the case of pre-rinse spray vales, restaurants and cafeterias.

The high estimate produced by FAWCET allows for ordinances adopting higher-efficiency standards and modifications to land development regulations. These strategies are very cost-effective and require changes in local rules and ordinances. The costs reflected in these BMPs are largely administrative costs associated with producing the rule changes, along with strategy and public relations meetings, as well as communicating the proposed changes to stakeholders and the public.

Other BMPs developed and used in the high estimate (and presented previously) include Waterwise Florida Landscape, advanced ET irrigation controllers, design-based residential irrigation audits, repair-based residential irrigation audits, high-efficiency dishwashers, and high-efficiency clothes washers. These are likely unique to the District's FAWCET tool. All BMPs in FAWCET can be toggled on and off to create high- and low-water conservation potential estimates. One of the constraints applied to these runs was a $3-per-thousand-gal limit. All options came in at under the $3 cap, due to this constraint. It was determined that water conservation efforts can reduce 2035 demand by 84 mil gal per day (mgd) to 214 mgd.

The estimate for Region 3, which is part of CFWI, was calculated using the Conserve Florida EZ Guide. The guide provides a limited number of BMPs (bottom left-hand side of Figure 23). The final results for Region 3 using the guide are still being determined. More information regarding Region 3 results can be obtained at http://cfwiwater.com in the CFWI draft plan.

The overall vision for FAWCET is a continuous improvement approach (see Figure 24) and includes a previously developed web-based implementation and tracking tool (WBITT), which is shown in Figure 25. The vision begins with a set of default values or assumptions. Ideally, survey information is collected from a representative sample size of each disaggregated sector and other characteristics. Data collected in the survey step would provide better assumptions as to existing flow rates and passive replacement estimates. The results would also include the

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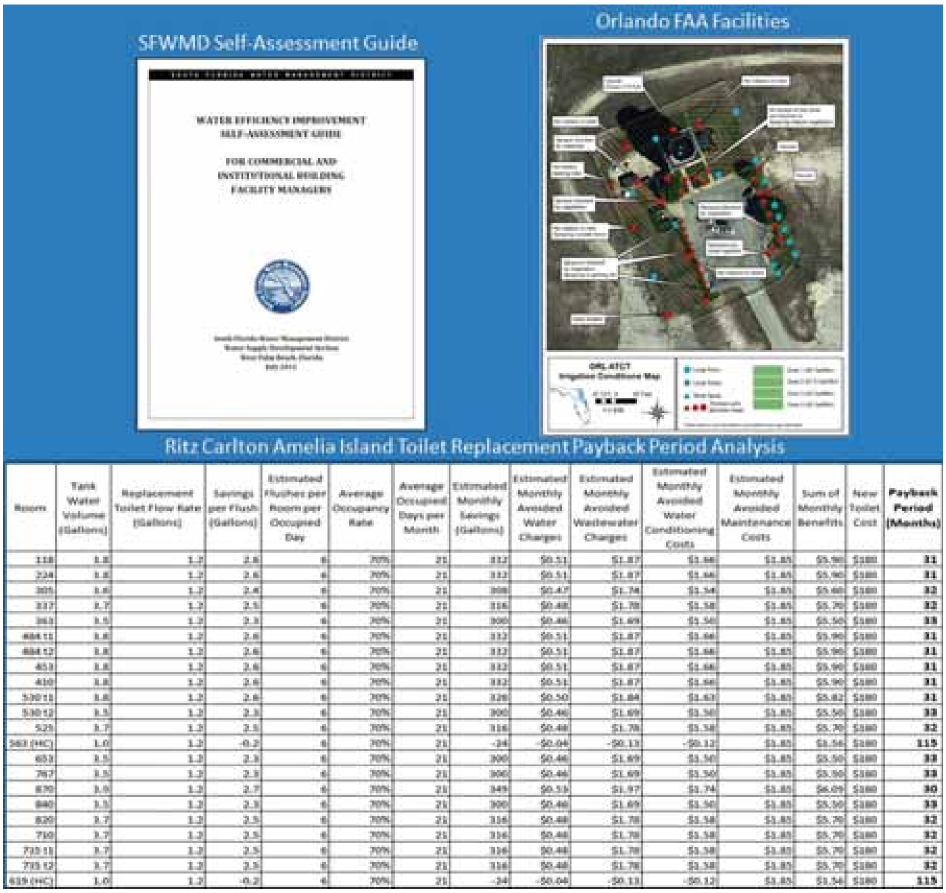
Figure 25. The web-based implementation and tracking tool (WBITT) tool was created to implement water conservation goal-based plans using ArcGIS Online. The tool can be used to run any number of utility-related programs.



Room	Tank Water Volume (Gallons)	Replacement Toilet Flow Rate (Gallons)	Savings per Flush (Gallons)	Estimated Flushes per Room per Occupied Day	Average Occupancy Rate	Average Occupied Days per Month	Estimated Monthly Savings (Gallons)	Estimated Monthly Avoided Water Charges	Estimated Monthly Avoided Wastewater Charges	Estimated Monthly Avoided Water Conditioning Costs	Estimated Monthly Avoided Maintenance Costs	Sum of Monthly Benefits	New Toilet Cost	**Payback Period (Months)**
118	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
224	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
305	3.6	1.2	2.4	6	70%	21	308	$0.47	$1.74	$1.54	$1.85	$5.60	$180	**32**
337	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
363	3.5	1.2	2.3	6	70%	21	300	$0.46	$1.69	$1.50	$1.85	$5.50	$180	**33**
484 11	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
484 12	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
453	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
410	3.8	1.2	2.6	6	70%	21	332	$0.51	$1.87	$1.66	$1.85	$5.90	$180	**31**
530 11	3.8	1.2	2.6	6	70%	21	326	$0.50	$1.84	$1.63	$1.85	$5.82	$180	**31**
530 12	3.5	1.2	2.3	6	70%	21	300	$0.46	$1.69	$1.50	$1.85	$5.50	$180	**33**
525	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
563 (HC)	1.0	1.2	-0.2	6	70%	21	-24	-$0.04	-$0.13	-$0.12	$1.85	$1.56	$180	**115**
653	3.5	1.2	2.3	6	70%	21	300	$0.46	$1.69	$1.50	$1.85	$5.50	$180	**33**
767	3.5	1.2	2.3	6	70%	21	300	$0.46	$1.69	$1.50	$1.85	$5.50	$180	**33**
870	3.9	1.2	2.7	6	70%	21	349	$0.53	$1.97	$1.74	$1.85	$6.09	$180	**30**
840	3.5	1.2	2.3	6	70%	21	300	$0.46	$1.69	$1.50	$1.85	$5.50	$180	**33**
820	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
710	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
733 11	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
733 12	3.7	1.2	2.5	6	70%	21	316	$0.48	$1.78	$1.58	$1.85	$5.70	$180	**32**
619 (HC)	1.0	1.2	-0.2	6	70%	21	-24	-$0.04	-$0.13	-$0.12	$1.85	$1.56	$180	**115**

Figure 26. A distinguishing characteristic of FAWCET is the ability to scale up or down to accommodate an individual facility. In this case, the model was run for the Orlando Executive Airport and Orlando international Airport.

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desired statistical confidence levels and intervals and margins of error.

The survey information is used to adjust the FAWCET assumptions in the assumptions tab. The analysis is carried out and a plan for implementation is developed, with the totals first being calibrated to existing water use projection methods, which combine MOR values and BEBR population projections. This calibration allows for better goal setting from a historical utility water use perspective. One goal could be to keep water use constant (and therefore, utility revenue) over the planning horizon while accommodating new growth, albeit at a higher efficiency per parcel.

The WBITT tool is then used to implement and track the program, collecting more field-verified results to add to the surveyed information through observations. A baseline of use is compared to the implemented BMPs to calculate the actual savings, helping to identify and further narrow the focus of the plan to only those BMPs and contractors that provide measurable savings and can be proven to produce a firm yield.

The WBITT tool is an ArcGIS Online application, which uses FAWCET outputs to track and manage the implementation of the plan. The FAWCET output parcels are represented by a heat map or recommended replacement fixtures map. Each parcel can be clicked on through a web-based Android or iPhone device. The record for the targeted parcel pops up; if that customer has responded to an offer for a rebate and arrangements have been made between the customer and utility, the audit is performed. While the fixtures are being replaced and the new data collected, adjustments made to the existing information are reflected in the database located in the Cloud or on District servers. ArcGIS Online has introduced several tools to manage many different utility-based programs using its service. ArcGIS Online allows developers to modify the structure of its application to suit the needs of the user; this is what the District has done to develop the WBITT tool. The District also modified WBITT to include the capability to administer an irrigation enforcement program, at the request of a customer utility. ArcGIS Online is highly customizable and can be used to administer a range of programs, such as cross-connection control or any other utility-based or local code enforcement programs.

One of the distinguishing features of FAWCET is its ability to scale up and down (see Figure 26). For example, if all the underlying data from an entire utility were deleted, except for a particular home, FAWCET would deliver a result maximizing the water savings within that home among its range of BMP options. The total budget would have to be modified to reflect a reasonable budget amount, in line with a typical home improvement budget of around $800 for the year. Using this feature, District staff, together with staff from the South Florida Water Management District, created a scaled down version of FAWCET to calculate the water conservation potential for two Federal Aviation Administration (FAA) facilities in Orlando.

A federal contractor contacted District staff and requested that a water conservation audit be performed at the Orlando Executive Airport and the Orlando International Airport. District staff used south Florida's water efficiency improvement self-assessment guide to estimate occupancy rates of various floors, requested visitor log statistics, and performed indoor and outdoor flow-rate tests and audits to refine the water use information provided by the meter or billing information. This occurred prior to the development of the WBITT tool. The data was processed through FAWCET and the resulting report was delivered to the contractor.

The Future

Future improvements to FAWCET include the development of another web-based tool that can access and query the District's FAWCET parcel-level water use data as an input. Currently, the tool is pointed through a file path to where the account-level data in the proper format is housed. The ability to cut and paste data into a web-based data window would be an improvement, and is being considered.

The next tool will make all of the reported options explicit for objective functions or constraints. Some of the reported information will have the ability to be viewed from a range of perspectives—utility, customer, district, and energy partner. The ArcGIS Online WBITT tool will be seamlessly connected to FAWCET. Work continues on an agricultural version of FAWCET, called the Florida Automated Agricultural Resource Model (FAARM). In the short run, FAARM will be used to produce high-level estimates of water conservation in agriculture from improved maintenance schedules or BMP options. These results will be used to demonstrate the potential for partnerships among utilities, the District, and agricultural producers. Early results have shown agricultural water conservation to be more competitive in cost per thousand gal, in comparison to the utility results from FAWCET.

The FAWCET continues to provide support for the District's four main initiatives. The tool will continue to be used to identify water conservation/demand management projects that will enhance existing plans for alternative and traditional water supply projects. Better data , including proxy and actual, will allow District staff to zero in on distinct utilities and sectors to compare and identify the most efficient uses and gather details, and then promote their practices among their peers (Castaneda, 2001).

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