Estimating Districtwide Water Conservation: St. Johns River Water Management District's Estimation Tool

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The St. Johns River Water Management District is continuing its development of the Florida Automated Water Conservation Estimation Tool (FAWCET), a water conservation planning tool developed by the District to support its initiatives by providing districtwide estimates of water conservation. It is being used, in some form, in four of the five state water management districts.

The FAWCET linear programming model calculates conservation potential by optimizing the selection of best management practices (BMPs) to maximize savings while minimizing costs. It estimates conservation savings for residential indoor; residential outdoor; and commercial, industrial, and institutional (CII) domestic use. A previous article was written that delved into the details of FAWCET optimization calculations[1], which provides background, and this article is an update to the latest developments in FAWCET and a glimpse into the future of what has become an invaluable tool for water use planning at the District.

Background

The FAWCET tool leverages county property appraiser data, census block data, and utility billing data to create a rich comma-separated value (CSV) data set for input into the tool. The tool then solves an optimization problem to determine the best number of implementations of each BMP; the resulting savings and cost is summarized for both residential and commercial sectors. Additional output for each sector includes: passive replacement savings (credit for existing utility conservation efforts), program replacement implementations, and additional cost and savings information, such as an annualized cost per 1,000 gal and mil gal per day (mgd), respectively.

This is a much improved way to estimate water conservation, because it provides a method to choose BMPs in a collectively exhaustive way, whereas previous spreadsheet-based estimation tools choose BMPs in a mutually exclusive way. The summary information produced by FAWCET allows for the development of a thorough planning effort for water conservation[1].

The FAWCET optimization analysis targets volume use reduction through the use of BMPs to maximize savings within a set budget, or it can be used as a multiobjective model to emphasize savings over budget—and vice versa—for the output.

The input data is used to develop heat maps, which illustrate where high, medium, and low water use is occurring throughout a utility service area. Sectors of use are associated with their characteristic water uses and their sector growth rate derived from the build dates of the parcels[1]. This data allows the District to disaggregate sectors by the number of parcels and their water use amounts. More importantly, the sector's water use can also be projected into the future for the purpose of quantifying water use, and ultimately, savings over a given planning horizon. Additional processing is required to further develop the database[1].

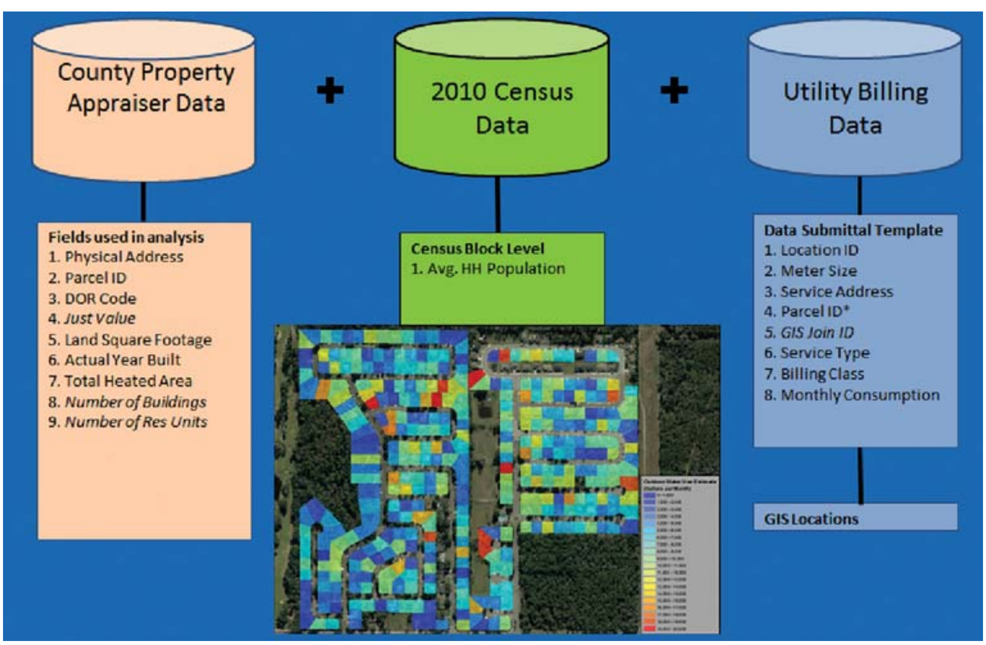

Figure 1. FAWCET leverages account-level billing data where available, or a proxy data set recently built for the entire state of Florida.

Data Preparation

Although much progress has been made in the development of automated metering devices, whether for radio-read or fixed-base systems, there remains a need to further disaggregate water use to establish indoor and outdoor use baselines[1]. The division between indoor and outdoor use is currently accomplished through the "minimum month" method, which considers indoor use to be defined as the lowest-use month in the parcel's monthly billing record to a maximum of 10,000 gal; the maximum is set to avoid counting winter watering, which is common in Florida. If the difference between the minimum month and the peak month for the year is greater than 10,000 gal, the parcel is identified as an in-ground irrigator; if the difference between the minimum month and the peak month is less than 10,000 gal, that residential parcel is identified as a hose irrigator[1]. Indoor water use is separated into proportions (Mayer and DeOreo, 1999); the study resulted in proportioning the indoor water use volume from toilets, faucets, showers, clothes washers, and other uses[1].

Building standards identify the number of bathrooms in a home per sq ft. This calculation allows for estimating fixtures within homes adjusted down to the number of fixtures a utility water conservation program would reasonably replace within a home. Both residential indoor and outdoor use and multifamily indoor-only use volumes and fixture counts are calculated using these methods[1].

Limited sectors of commercial properties and their fixture estimates are calculated through the use of the number of bathrooms per sq ft; examples of these sectors include hospitals, hotels, schools, and live-in care facilities. The number of bathrooms per sq ft as specified in the building standards are also used for these sectors to estimate the number of bathrooms, and therefore, replaceable fixtures, while a water use per sq ft metric is used where account-level billing data is not available. In addition, the parcels are disaggregated further, initially into plumbing-code eras[1]. The plumbing code-based build-outs are defined in the following way:

- Build-Out 1 (BO1) 1984 and earlier: pre-plumbing code standard
- Build-Out 2 (BO2) 1985-1993: National Plumbing Code Standard
- Build-Out 3 (BO3) 1994 to present: Federal Energy Act
- Build-Out 4 (BO4) Future: current or BO3 efficiencies assumed

In spring 2014 the District hired a consultant to create a statewide data base that was developed using actual account-level data. The data was developed utilizing load profiles of billing data from 26 utilities. The profiles represent a profile of customer use through a graph that displays the customer single-family consumption at 1000-gal-use intervals on the x-axis and the percentage of customers on the y-axis at each 1,000-gal-use interval. The graph is weighted by the number of customers in each of the 26 utilities that make up the load profile. The weighted load profile was used to develop the statewide water use database by distributing these estimated residential water use volumes randomly throughout a service area.

When the load profiles are used to estimate single-family use and compared to the actual account-level billing data, the method has proven to be a more accurate way of characterizing water use. The previous method used to estimate single-family residential water use applied water use coefficients multiplied by the sq ft of the heated area; this method is currently used in calculating domestic water uses in commercial facilities where account-level data is not available. A statewide data base was developed using the methodologies described previously. The data is used for estimating land-applied water for groundwater modeling purposes, as well as conservation[5].

Creating the Build-Out 4 Database Tool

In the summer of 2014, the District hired a consultant to limit the fields in the statewide water use database to a restricted number of columns of data necessary to use as an input file for FAWCET. While the creation of a statewide database is beneficial for the District in developing water conservation estimates using FAWCET, the creation of the "Create Build-Out 4 Data Base" tool (CBO4-DB) has also been critical to the process; prior to its development, the future build-out was being processed manually. The CBO4-DB uses the county appraiser database trends in residential and commercial parcel year-built dates to derive a growth rate for each sector and project the growth of each sector over a selected planning horizon. The CBO4-DB tool is housed within a custom ArcGIS 10 toolbox.

This process creates future parcels for all sectors, from single-family to multifamily and the other CII sectors. The tool then randomly selects parcels of the most recent build dates within the past decade or so and a separate input file is created and joined manually to the original BO1-BO3 file set[5].

A general outline of the steps involved began with CBO4-DB, prompting the user to access the statewide data base and outline an area of interest within the ArcGIS 10 map environment (Figure 3)[5].

The area of interest in the figure is outlined using one of the service-area boundaries in ArcGIS 10, or a custom service area boundary. The underlying data is also labeled by the service

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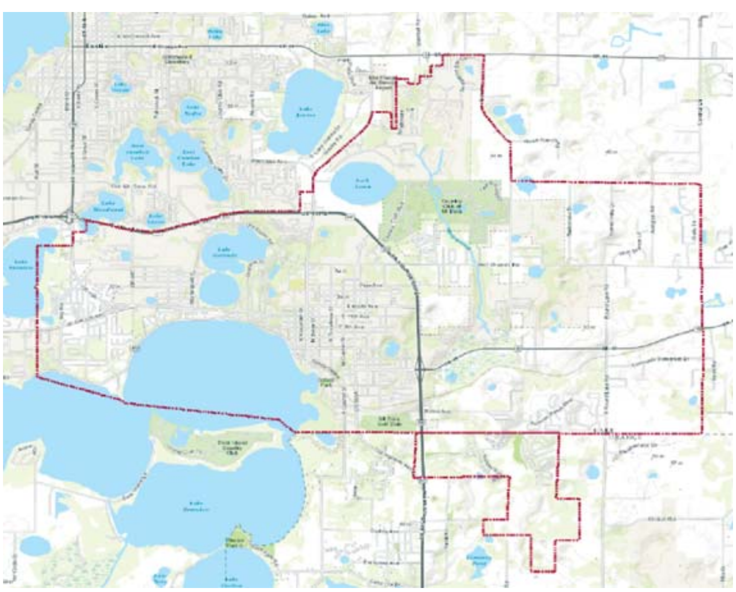

Figure 3. The area of interest is outlined using ArcGIS 10.

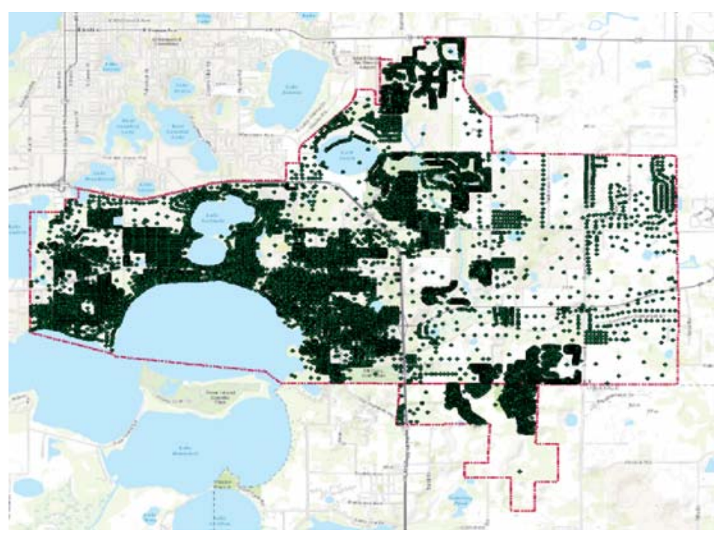

Figure 4. Parcels within a service area are turned on in ArcGIS 10.

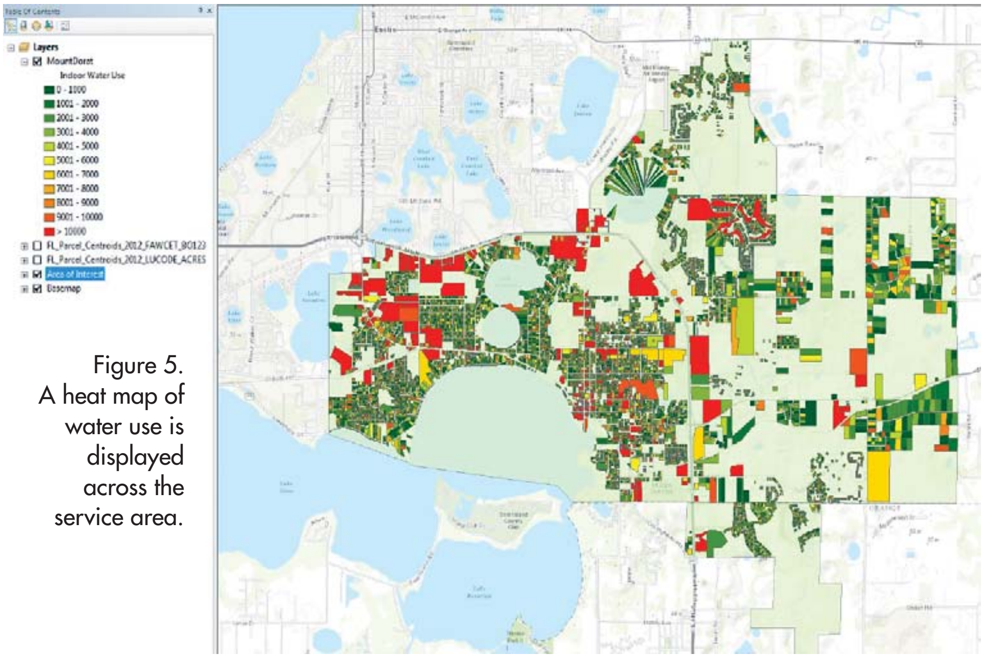

Figure 5. A heat map of water use is displayed across the service area.

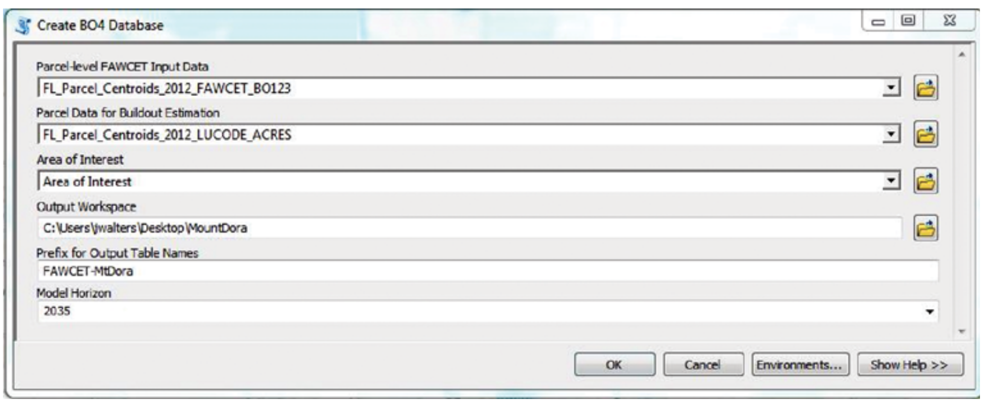

Figure 6. Sequential prompts from the CBO4-DB for developing a BO4 projection.

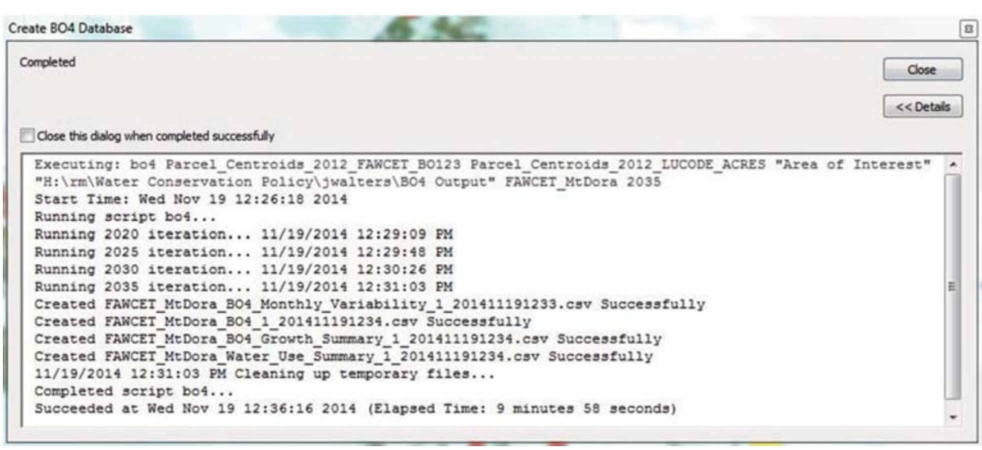

Figure 7. The progress of the development of the BO4 projection is shown in the dialog box.

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provider and the city. Once selected, the parcels are brought into the selected area (Figure 4)[5].

The underlying data records are populated with indoor and outdoor water use estimates, along with the details used to develop existing fixture estimates. This data is represented as heat maps, which show the range of water use across the selected service area parcels. The data represented can either be based on load profiles or actual account-level billing data, where available (Figure 5)[5].

The CBO4-DB was created using Python programming language and runs as a custom ArcGIS tool that forms part of the FAWCET toolbox. A more detailed description of the steps begins with the CBO4-DB, prompting the user to browse to the filepath for the parcel-level FAWCET input data, which includes BO1, BO2, and BO3 (Figure 6). This is the location of the underlying baseline data being used to develop BO4. The user is prompted to provide the filepath for the location of the parcel data for build-out estimation, which represents the total area available for future build-out. The "area of interest" selection step allows the future growth rates of the parcels to be represented by the most recent build-out standards.

This tool randomly selects sectors and parcels from BO3 to represent the types of parcels that will be built in the future. It is designed to more accurately estimate the most recent trends in lot size and heated areas and to avoid selecting older trends in building sizes. For example, more homes are being built with more sq ft, while lot sizes are being kept smaller because of cost and for ease of maintenance. This overall trend may not be true in a specific area of interest however, and so randomly selected parcels are developed from local data and represent local trends, depending on the area selected.

The user is then prompted by CBO4-DB to select the output workspace. This is the file path that identifies where the resulting files will be saved. A prefix for the table-names prompt allows the user to name the files for future reference. A model horizon step is used to specify the number of years being considered for a planning horizon. Typically for District purposes, a 20-year planning horizon is used[5].

Once the file path and information is entered in the BO4 tool, the user is prompted to press the "OK" button.

The processing window shows the progress of the BO4 tool script, as it accesses the necessary files and develops the projection in five-year increments (Figure 7). Three additional tables illustrate the results: monthly variability, growth summary, and water use summary. With this in-

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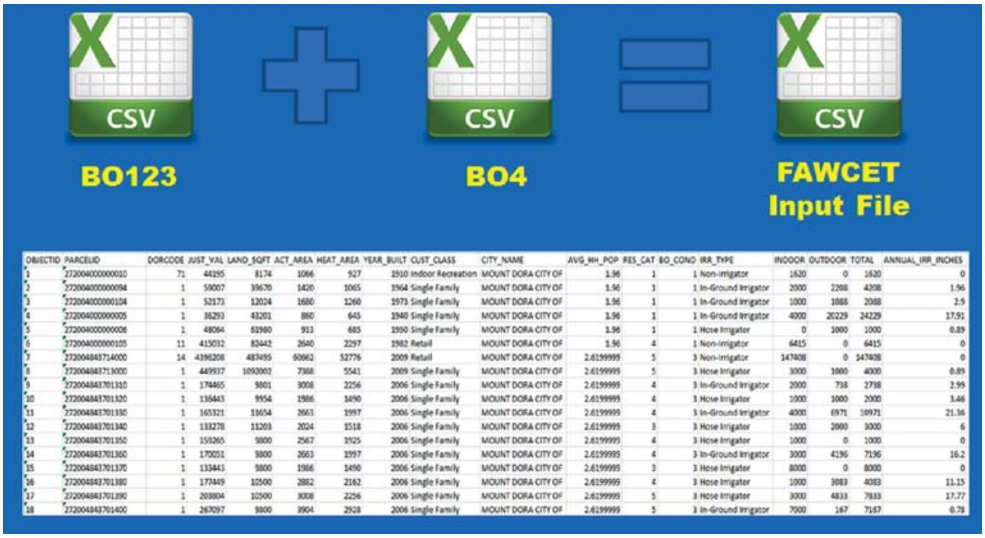

OBJECTID	PARCELID	DORCODE	JUST_VAL	LAND_SQFT	ACT_AREA	HEAT_AREA	YEAR_BUILT	CUST_CLASS	CITY_NAME	AVG_HH_POP	RES_CAT	BO_COND	IRR_TYPE	INDOOR	OUTDOOR	TOTAL	ANNUAL_IRR_INCHES
1	27200400000010	71	44195	8174	1066	927	1910	Indoor Recreation	MOUNT DORA CITY OF	1.96	1	1	Non-Irrigator	1620	0	1620	0
2	27200400000094	1	59007	39670	1420	1065	1964	Single Family	MOUNT DORA CITY OF	1.96	1	1	In-Ground Irrigator	2000	2208	4208	1.96
3	27200400000104	1	52171	12024	1680	1260	1973	Single Family	MOUNT DORA CITY OF	1.96	1	1	In-Ground Irrigator	1000	1088	2088	2.9
4	27200400000005	1	36293	43201	860	645	1940	Single Family	MOUNT DORA CITY OF	1.96	1	1	In-Ground Irrigator	4000	20229	24229	17.91
5	27200400000006	1	48064	61980	913	685	1950	Single Family	MOUNT DORA CITY OF	1.96	1	1	Hose Irrigator	0	1000	1000	0.89
6	27200400000105	11	415032	82442	2640	2297	1982	Retail	MOUNT DORA CITY OF	1.96	4	1	Non-Irrigator	6415	0	6415	0
7	272004843714000	14	4396208	487495	60662	52776	2009	Retail	MOUNT DORA CITY OF	2.6199999	5	3	Non-Irrigator	147408	0	147408	0
8	272004843713000	1	449937	1092002	7388	5541	2009	Single Family	MOUNT DORA CITY OF	2.6199999	5	3	Hose Irrigator	3000	1000	4000	0.89
9	272004843701310	1	174465	9801	3008	2256	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	In-Ground Irrigator	2000	738	2738	2.99
10	272004843701320	1	136443	9954	1986	1490	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	Hose Irrigator	1000	1000	2000	3.46
11	272004843701330	1	165321	11654	2663	1997	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	In-Ground Irrigator	4000	6971	10971	21.36
12	272004843701340	1	133278	11203	2024	1518	2006	Single Family	MOUNT DORA CITY OF	2.6199999	3	3	Hose Irrigator	1000	2000	3000	6
13	272004843701350	1	159265	9800	2567	1925	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	Hose Irrigator	1000	0	1000	0
14	272004843701360	1	170051	9800	2663	1997	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	In-Ground Irrigator	3000	4196	7196	16.2
15	272004843701370	1	133443	9800	1986	1490	2006	Single Family	MOUNT DORA CITY OF	2.6199999	3	3	Hose Irrigator	8000	0	8000	0
16	272004843701380	1	177449	10500	2882	2162	2006	Single Family	MOUNT DORA CITY OF	2.6199999	4	3	Hose Irrigator	1000	3083	4083	11.15
17	272004843701390	1	203804	10500	3008	2256	2006	Single Family	MOUNT DORA CITY OF	2.6199999	5	3	Hose Irrigator	3000	4833	7833	17.77
18	272004843701400	1	267097	9800	3904	2928	2006	Single Family	MOUNT DORA CITY OF	2.6199999	5	3	In-Ground Irrigator	7000	167	7167	0.78

Figure 8. The BO4 files are generated for use in the FAWCET model. The BO4 result is manually appended to the existing BO1-3 files. The table in the graph represents the limited input in CSV format required to run FAWCET.

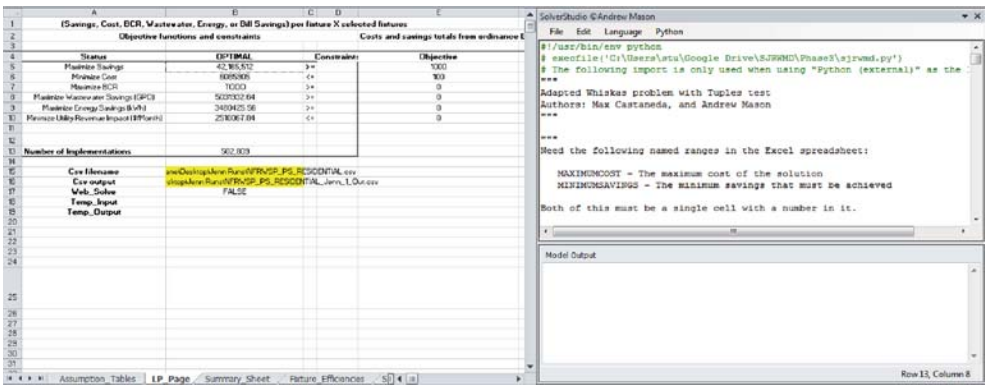

Figure 9. The FAWCET LP page worksheet is used to define the problem objective and constraints.

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formation, growth and water use summaries generated by CBO5-DB can be compared to previously developed water use summaries in a localized area, developed through the most recent District water use planning cycle.

These tables are generated as a guideline for comparison purposes and are not intended to replace District-derived estimates. Growth-rate summaries are compared to available land to ensure the growth rate from the parcels identified in CBO4-DB does not exceed the land available for development. In the event the water use or growth rate exceeds that calculated by the tool, the results can be adjusted up or down to adhere to the pre-established projections and available land calculated by the tool (Figure 8)[5].

Finishing Up With the FAWCET

Once the BO4 file is appended to the BO1-3 files, the data is ready for input into the latest version of FAWCET[1]. This data is used by FAWCET to calculate the water savings and costs for all the different BMP interventions that may be made at each of the residential and commercial premises under consideration. It is then used to determine the best set of BMP interventions to optimize some user-specified combination of quality measures.

Written in Excel, FAWCET has optimization modelling provided by SolverStudio, a free Excel add-in[3]. A number of different worksheets are

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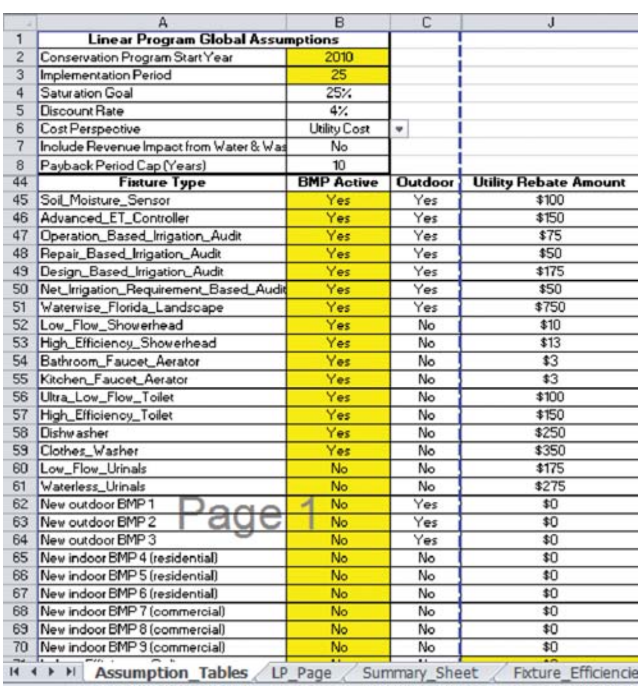

	A	B	C	J
1	**Linear Program Global Assumptions**			
2	Conservation Program Start Year	2010		
3	Implementation Period	25		
4	Saturation Goal	25%		
5	Discount Rate	4%		
6	Cost Perspective	Utility Cost		
7	Include Revenue Impact from Water & Was	No		
8	Payback Period Cap (Years)	10		
44	**Fixture Type**	**BMP Active**	**Outdoor**	**Utility Rebate Amount**
45	Soil_Moisture_Sensor	Yes	Yes	$100
46	Advanced_ET_Controller	Yes	Yes	$150
47	Operation_Based_Irrigation_Audit	Yes	Yes	$75
48	Repair_Based_Irrigation_Audit	Yes	Yes	$50
49	Design_Based_Irrigation_Audit	Yes	Yes	$175
50	Net_Irrigation_Requirement_Based_Audit	Yes	Yes	$50
51	Waterwise_Florida_Landscape	Yes	Yes	$750
52	Low_Flow_Showerhead	Yes	No	$10
53	High_Efficiency_Showerhead	Yes	No	$13
54	Bathroom_Faucet_Aerator	Yes	No	$3
55	Kitchen_Faucet_Aerator	Yes	No	$3
56	Ultra_Low_Flow_Toilet	Yes	No	$100
57	High_Efficiency_Toilet	Yes	No	$150
58	Dishwasher	Yes	No	$250
59	Clothes_Washer	Yes	No	$350
60	Low_Flow_Urinals	No	No	$175
61	Waterless_Urinals	No	No	$275
62	New outdoor BMP 1	No	Yes	$0
63	New outdoor BMP 2	No	Yes	$0
64	New outdoor BMP 3	No	Yes	$0
65	New indoor BMP 4 (residential)	No	No	$0
66	New indoor BMP 5 (residential)	No	No	$0
67	New indoor BMP 6 (residential)	No	No	$0
68	New indoor BMP 7 (commercial)	No	No	$0
69	New indoor BMP 8 (commercial)	No	No	$0
70	New indoor BMP 9 (commercial)	No	No	$0

Figure 10. In the assumptions tables tab, the user designates the start-year B2, the implementation period B3, the cost perspective B6, the active BMPs B45-71, and the utility rebate cost J45-71.

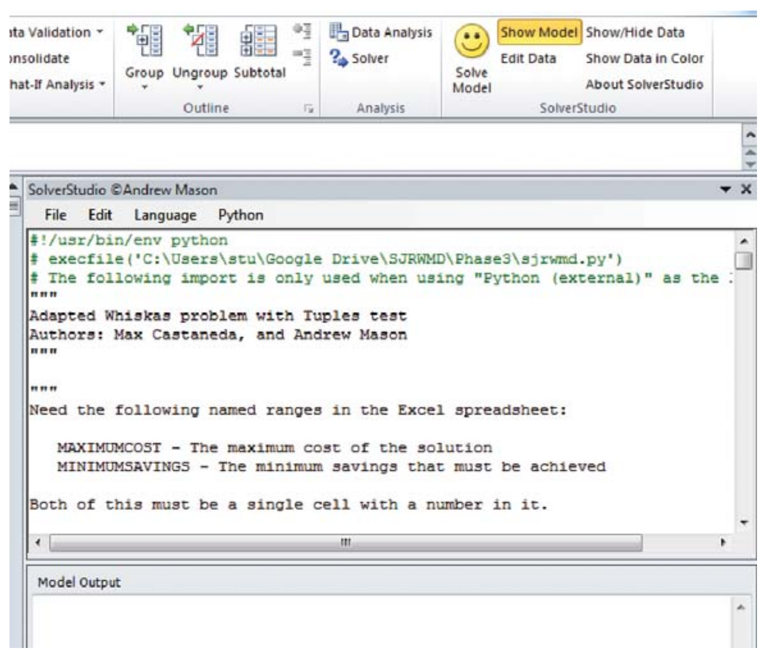

Figure 11. The FAWCET model is written using PuLP, a library for the Python-based scripting language that enables users to describe mathematical programs[6]. The SolverStudio add-in is used to embed the PuLP code into the Excel spreadsheet, providing a familiar environment for the FAWCET model user[3].

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used to set up the problem data, define the optimization problem to be solved, and then, after optimizing, present summary tables for the solution.

The core FAWCET worksheet is the "LP page" where the user specifies the input BO4 file and the output CSV file, and defines the particular optimization problem (i.e., linear program) to be solved. As Figure 9 shows, the user can specify (via column E) the weights that are used to combine a number of different quality measures together to give a single overall objective value to be maximised. This worksheet also allows the user to specify (via column D) minimum or maximum values (i.e., constraints) for each of these quality measures. This combination of user-specified weights and constraints for each quality measure gives the user a lot of flexibility in defining a particular problem of interest.

Prior to processing, the user must also designate various parameters, such as the start-year of the planning horizon period, the BMPs that will be active through the analysis period, and the rebate amounts or costs for each BMP. The user can specify a "cost perspective" that allows for focus, for example, on the cost to the utility, the cost to the customer, or the sum of both. These and other parameters are set using the worksheet shown in Figure 10[5].

Once the problem has been specified, the user clicks the SolverStudio solve button, shown in Figure 11. This instructs SolverStudio to solve the optimization model to determine the best BMP interventions. The underlying integer linear programming model that determines these optimal interventions is written using the PuLP Python-based modelling system6, and is solved using the COIN-OR CBC solver (COIN-OR 2015)[1].

The results are optimized selections of water-conserving BMPs, given a utility's unique customer base. The results are summarized in the summary sheet tab, which reports the total passive and program replacements for residential and commercial sectors; it also summarizes the cost and the annualized cost per 1,000 gal and other useful data that can be used to populate return on investment (ROI) calculations (Figure 12)[1].

Merging the input file used to run FAWCET and the output file generated by the FAWCET run provides much greater detail in terms of the account types chosen for various BMPs and their volume of average annual month. As Figure 13 shows, this information can be developed graphically. If proxy data has been used, then an Excel pivot table is used to develop an approach for targeting certain types of customers by their annual average month volume. If the data used is account-level billing data, the results can be mapped using the parcel identification, and the resulting map can be used to target moderate or high-using areas and to stage a logistical plan over a portion of the planning horizon or the entire 20-year planning horizon[1].

Figure 13. FAWCET develops estimates of the water conserved by parcel utilitywide.

Conclusion

The District is currently using FAWCET to develop regional water conservation estimates over the District's five regional water planning groups or areas. It is also being used as a first step in the development of water conservation program estimates for the development of proposals for the District's cost-share program. It will be used as an option to assess the results of water conservation cost-share programs in the required program evaluation step.

The District is planning to develop these tools into one easy-to-use format. While BO1-3 data is currently accessed through ArcGIS 10, the District maintains an ArcGIS online account that could be used to house the data and make it available to a wider group of users than currently use the tools. Both FAWCET and the CBO4-DB are Python-based tools that typically run on a user's own computer. However, FAWCET can also solve the optimization models in the cloud using an Amazon EC-squared account with Gurobi, a commercial optimization solver for various types of programming and one of the most powerful on the market.

It makes sense to continue to develop the tool to work seamlessly as a Python-based tool accessible over the cloud; however, this has yet to be discussed and decided by the District. For now, District staff members have been distributing the Excel-based spreadsheet and providing the necessary ArcGIS layers and CBO4-DB tool to run FAWCET. District staff cannot support the tools, but may be able to perform runs for given areas provided the data is available for the area of interest.

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