St. Johns River Water Management District Agricultural Irrigation and Conservation Benefit-Cost Optimization Tool for Mega Model Area

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Agricultural (Ag) water use represents a major portion of Florida's conservation potential. The St. Johns River Water Management District (District) hired Royal Consulting Services Inc. (RCS) to evaluate the amount of potential Ag water conservation within the District and irrigation consumption estimates for recharge credit estimates in areas of the Peninsular Florida and Southeast Georgia groundwater modeling domain (Figure 1). This area is analogous to the United States Geological Survey (USGS) "mega model" extent (Sepulveda, 2012). This study uses a linear programming (LP) model to optimize water conservation relative to cost.

In addition to the LP analysis of cost and water savings, a benefit-cost analysis will evaluate future conservation efforts from several perspectives: the producer, the District, potential utility partners, and water resources in general. Some of the benefits will include: reduced energy or fuel; reduced fertilizer, pesticide, and herbicide use; reduced operation and maintenance (O&M) expenses; reduced water withdrawals; reduced total maximum daily load (TMDL); and avoided permitting and/or expansion costs. The LP tool is modeled after the District's similar work estimating conservation potential for public supply utilities at the account level. This work will be an ongoing collaborative approach, using input from producers, Florida Department of Agriculture and Consumer Services, universities, industry experts, and District staff. In addition to the Ag water conservation aspect, this project will also develop estimates of Ag irrigation water use for the entire study area representing 1995 and 2010 conditions.

Background

The District developed several water conservation planning tools based on LP methods for evaluating the water conservation potential of an optimized selection of best management practices (BMPs) for public supply utilities. Two versions of these tools have been featured in the August 2011 and August 2012 issues of the *Florida Water Resources Journal*. The tools generally rely on current regional end-use and efficiency studies, paired with account-level historical consumption data where available, as well as generally accepted water-use estimates to project the potential for water savings and associated costs. The LP planning

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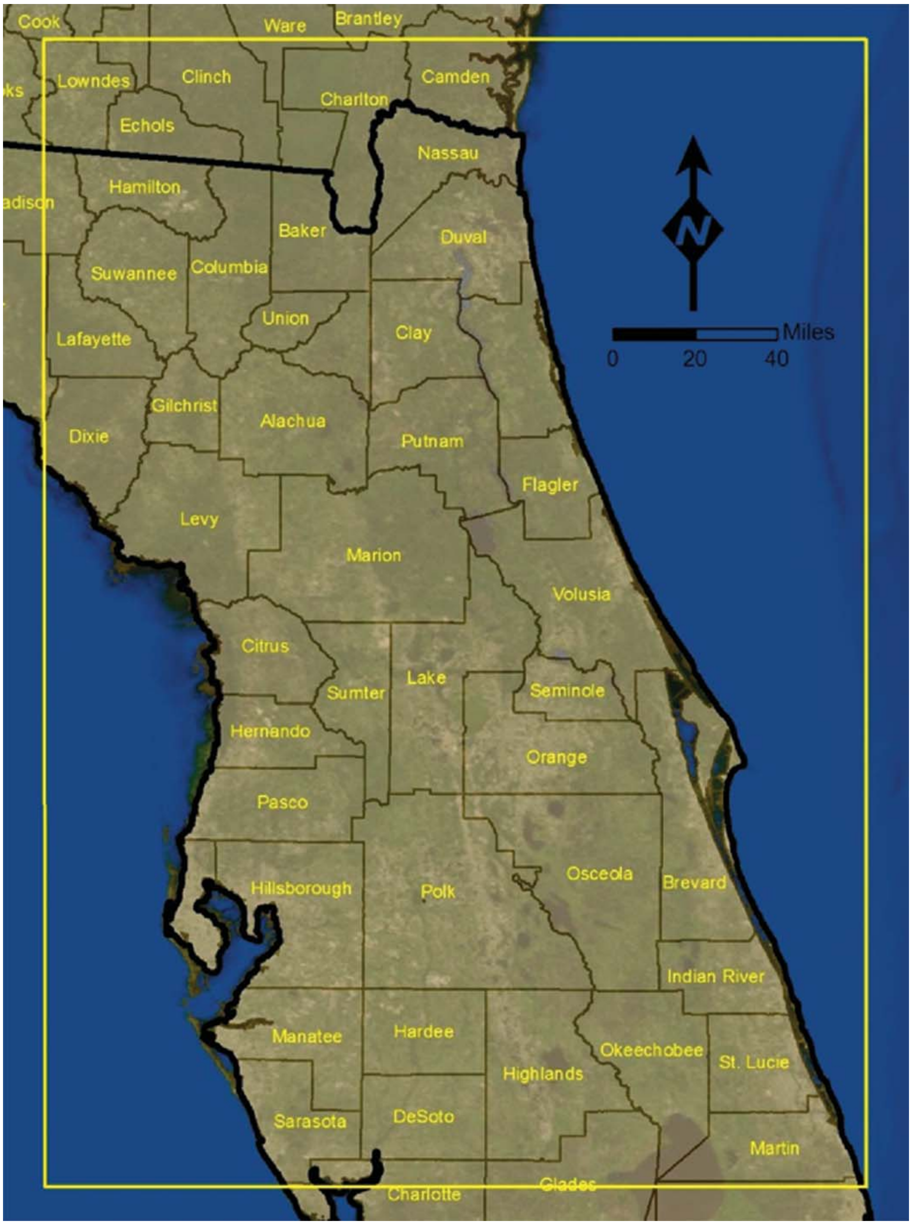

Figure 1. Study Area

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tools analyze historical water use for each permit holder or utility account individually for both indoor and outdoor use, and apply water conservation BMPs and their associated cost to optimize their selection. The LP tool executes optimization routines to identify and estimate the costs and benefits of water conservation at the parcel level. This level resolution allows a utility conservation coordinator to customize and optimize water conservation programs on a customer-by-customer basis.

Recognizing the vast potential for additional water savings within the Ag sector, the District hired RCS to study and apply these principles to Ag irrigation. The LP tool used for public supply utilities was modified to fit the various factors involving Ag irrigation water use; its name is the comparative farm agricultural (water) conservation tool (CFACT). The CFACT currently contains a list of crops, commonly used irrigation systems and efficiency, the cost for constructing new irrigation systems, and a relationship between maintenance costs and resulting irrigation efficiency within each irrigation type.

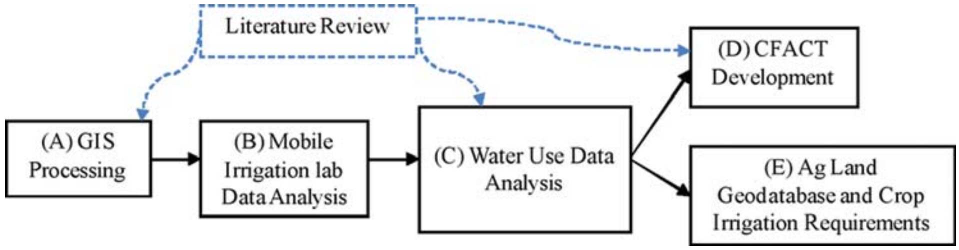

Figure 2. Project Workflow Chart

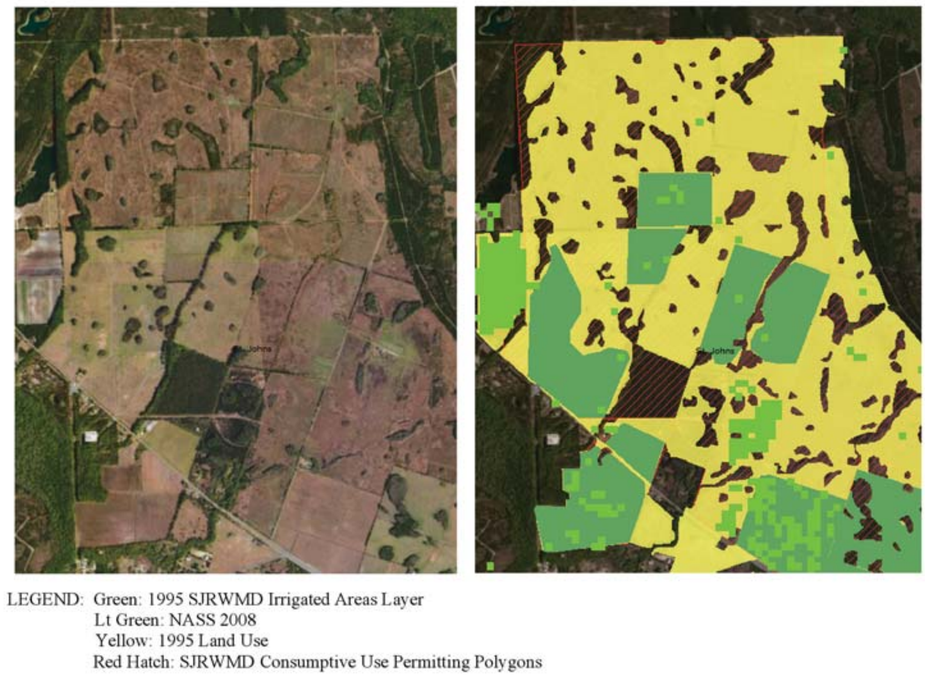

Figure 3. Example of GIS Overlay Process

Project Objectives

There are two principal objectives for the current study: (1) develop the base assumptions of irrigation efficiencies and cost factors associated with the various types of irrigation systems and crops grown within the study area; and (2) develop an Ag land geodatabase and associated farm-level irrigation estimates for 1995 and 2010 conditions.

The base assumptions developed in the first objective will form the basis for the first fully functional version of the CFACT. Due to the many variables related to Ag irrigation (system type, crops, region, cultivation practices, etc.) and the immense size of the study area (approx. 56,500 sq mi), it will be necessary to make simplifying assumptions. To the extent possible, detailed assumptions will be developed for predominant crops and irrigation systems. However, the purpose of the current phase of the CFACT is to develop planning-level estimates that will be used to identify key areas (regions, crops, and/or irrigation systems on the whole) for focusing future water conservation efforts. Furthermore, the structure of the CFACT will be designed to accommodate the addition of more detail at a later date.

The second objective will utilize available geographic information systems (GIS) information (e.g., coverages of irrigated areas, land use, crop satellite imagery, and consumptive/water use permitting data and mobile irrigation lab [MIL] data) to develop a comprehensive compilation of Ag lands in the study area. While emphasis is placed on irrigated areas, nonirrigated areas are picked up in the process and included as a secondary data set. For the irrigated areas, monthly estimates of irrigation are prepared to represent average, dry, and wet years.

Approach

The first task of this project involved an extensive literature review and interaction with numerous subject matter experts. The purpose of this effort was to compile as much information as possible to support the assumptions necessary for the CFACT and Ag land geodatabase. The required information includes, but is not limited to, the following:

- Factors influencing irrigation efficiency, such as the type of irrigation system, irrigation water management practices (e.g., when and how much water is applied), the design and maintenance of the system, conveyance losses, and storage losses
- Fuel, fertigation, and chemigation costs
- Costs of irrigation systems (fixed costs for new systems, operation, and maintenance)
- Crop water use profiles and typical growing seasons

Once the initial literature review was completed, the order of subtasks was executed, as shown in Figure 2.

GIS Data Processing

Currently there is no sole source of GIS data that defines the crop types, acreages, and irrigation systems throughout the entire study area. Therefore, several sources of information

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were overlaid and the most reliable information was utilized. For the current study, the data sources consist of:

(1) *Irrigated Areas Layers*. This type of GIS coverage would generally be assembled by the water management district. This level of data is more detailed than the typical water/consumptive use permitting polygons commonly provided by the water management districts, and represents the actual irrigated areas.

(2) *Water/Consumptive Use Layers*. This type of GIS coverage is prepared by the water management district. Generally, the polygon area for this type of coverage represents the permittee's total site area, whether it is irrigated or not.

(3) *Land Use/Land Cover Layers*. For the state, this data utilizes the Florida land use and cover classification system (FLUCCS) and is available at various yearly intervals (depending on the water management district). However, this classification system is not used in Georgia. Similar data for Georgia use a different classification system, but is too vague to define the crop type.

(4) *USDA NASS Crop Layers*. Prepared by the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), this data source was developed using infrared satellite imagery and is available for the entire study area for 2008 and 2010.

Figure 3 shows an example of how these data appear when overlaid together. In most situations, the District-irrigated area's polygons are the most reliable sources of information. As expected, the consumptive use permitting (CUP) polygons pick up the entire project site. The FLUCCS data (only level 2000 shown in this figure) are useful at identifying all agricultural areas, irrigated or not. The NASS data are generally less reliable for this project; however, some crops show up better than others and this source of information provides useful information on the crop type and was used in some instances to fill in data gaps. In Figure 3, only the irrigated areas polygons were considered to be irrigated land. The other areas picked up in this analysis were retained and can be used as a guide for future refinement.

Mobile Irrigation Lab Data Analysis

The District has funded many MIL audits through the Florida Department of Agricultural and Consumer Services (FDACS). Current data were initially made available from Volusia, Putnam, and St. Johns counties. This data set was expanded to a larger coverage area through further cooperation with FDACS. A MIL audit typically consists of an interview with the producer and a site-specific investigation to identify leaks, problems with application uniformities, and other irrigation water management shortcomings.

For this project, the MIL data were provided in a format such that the information could not be associated to any particular farm, only to a particular county, crop, and irrigation system type. It is speculated that the purpose of this anonymity is to promote honest interviews and evaluations. The purpose of analyzing the data for this project was primarily to assign an initial management-level characterization and irrigation efficiency by which the CFACT will judge potential water conservation measures.

Data from a total of 403 MIL audits were analyzed for the three counties listed within the District. Table 1 provides a preliminary abridged summary of the most frequently tested irrigation systems and crops and the most frequently observed problem types. This table will be updated when additional data are received from FDACS.

Overall, the most frequently occurring problem is the lack of an irrigation water management plan (78 percent of sites audited). Such a plan provides detailed operating procedures based on the site and design of the system, such as the maximum and recommended allowable depletion of soil moisture before an irrigation event should occur, the amount of water that should be applied and associated system run times, and the number of days to delay irrigation after a rain event. Other common management-related problems were a lack of a rain shut-off device (28 percent) or soil moisture measuring device and/or rain gauge (28 percent). This latter set of issues was not commonly found in micro-irrigation systems. Leaks and broken valves were identified

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Table 1. Mobile Irrigation Lab Data Analysis Summary (abridged)

Irrigation System	Micro	Micro	Solid Set	Sprinkler	All Crops and Irrigation Systems
Crop	Citrus	Container Nursery	Field Nursery	Field Nursery	
Total Number of MIL Sites	90	31	42	49	352
Problem					
Pressure variation due to elevation differences	38 percent	42 percent	0 percent	2 percent	**14 percent**
Mixed sprinkler/emitter sizes and unmatched precipitation in the same zone	37 percent	61 percent	24 percent	6 percent	**24 percent**
Mixed sprinkler/emitter brands or types in the same zone	9 percent	0 percent	38 percent	35 percent	**17 percent**
Poor emitter/sprinkler uniformity due to worn orifice	4 percent	0 percent	48 percent	16 percent	**12 percent**
Poor overlap due to improper sprinkler/emitter alignment or spacing	0 percent	0 percent	5 percent	22 percent	**11 percent**
Emitter/sprinkler spacing varies in same zone	0 percent	0 percent	2 percent	45 percent	**11 percent**
Missing/malfunctioning emitters or sprinklers	26 percent	23 percent	12 percent	14 percent	**17 percent**
Leaks and broken valves, pipe, laterals lines (poly-tubing), emitters, sprinklers	63 percent	94 percent	19 percent	31 percent	**40 percent**
Clogged emitters/nozzles (due to biological, chemical or physical factors)	76 percent	94 percent	19 percent	41 percent	**50 percent**
No rain shut-off device	8 percent	3 percent	62 percent	71 percent	**28 percent**
No soil moisture measuring device or rain gage	10 percent	0 percent	76 percent	51 percent	**28 percent**
No irrigation water management plan	80 percent	100 percent	100 percent	69 percent	**78 percent**
Average emission or distribution uniformity	72.1 percent	75.7 percent	66.5 percent	64.3 percent	
Emission or distribution uniformity rating[1]	Fair	Fair	Poor	Poor	

[1]Mobile Irrigation Lab Handbook (NRCS and FDACS, 2011)

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in 40 percent of the sites audited and this problem was most commonly found in the micro-irrigation systems. Clogged emitters or nozzles were found in 50 percent of the sites audited.

Another useful characteristic determined during the MIL audit is the emission uniformity (for micro-irrigation systems) and distribution uniformity (for sprinkler systems). This metric measures the uniformity by which water is distributed to the individual trees or plants or to the field surface. This information does not directly indicate whether a crop is over-irrigated to compensate for low uniformity. However, with the low frequency of sites having irrigation water management plans, it can be reasonably assumed that producers will typically opt to overwater to a certain extent, as opposed to having deficit irrigation and risk sacrificing crop yield.

Water Use Data Analysis

The District requires permitted water users to submit monthly estimates of the amount of water withdrawn for the purposes of irrigation or other uses. This information is commonly referred to as "EN50" data. Monthly EN50 data from 2007 to 2012 were compiled for nearly all (98.7 percent) of the Ag water use permit GIS polygon coverage. It was initially envisioned that EN50 data would be given first priority for use in the CFACT and Ag land geodatabase. For sites without this information, many located outside the SJRWMD, results from the crop water demand agriculture field-scale irrigation requirements simulation (AFSIRS) model (Smajstrla, 1990) would be used.

However, when the EN50 data were initially linked to the Ag land geodatabase and normalized for irrigated area, some issues were identified. In many instances the amount of water used exceeded 1,000 in. per year, well outside of a normal range for the crop; these observations most commonly occurred for smaller sites. For small sites, a GIS discrepancy of 20 or 30 acres (which is insignificant relative to the approximately 300,000 acres included in the District's irrigated areas coverage) can lead to large errors when the per-acre water use is calculated. Other potential sources of these discrepancies include the accuracy of the meter reading data, seasonal and year-to-year changes in planted acreage, leaks, and others.

CFACT Development

Initially, the CFACT was designed to display groups of farms in a table format with information details regarding the irrigation system, crop type, irrigated area, the crop's net water requirement, and an assumed O&M condition (deferred, reactive, and proactive). The base assumptions in the model consist of a set of irrigation efficiencies by irrigation type and by O&M condition, O&M costs, and new system costs. In some cases, a change to the irrigation type would require modification of cultivation practices, but incorporating this level of detail and variability is beyond the current scope of this project. In addition, an irrigation suitability matrix is used to limit the potential irrigation possibility based on the type of crop being grown.

The CFACT runs within Microsoft Excel with the OpenSolver add-in (www.opensolver.org). The model is set up in such a way that the user will input the amount of funds available for modifications and a water conservation goal. Once these variables are set, the solver routine will find the optimal scenario that maximizes the amount of water conserved, utilizing the upper limits of funds available.

The Relationship Between Irrigation Efficiency and Operation and Maintenance

One of the main tasks of this project was to improve the initial SJRWMD model assumptions. To this end, the Natural Resources Conservation Service (NRCS) farm irrigation rating method (FIRM) was implemented. The FIRM is typically used for irrigation audits to assess the actual efficiency of existing systems and evaluate the potential benefits from improved maintenance practices or the design.

To understand how the FIRM works, it is necessary to understand the basic theory regarding irrigation efficiency. For the current study, the term "irrigation efficiency" refers to the amount of water delivered to the crop divided by the amount of water withdrawn. The "net" irrigation requirement refers to the amount of water needed to prevent undesirable crop water stress, assuming a 100 percent efficient system and "gross" irrigation requirement factors in a system's irrigation efficiency. While this philosophy towards irrigation may be useful from a water management and conservation perspective, from a farmer's perspective, the more meaningful definition of irrigation efficiency is the effectiveness of an irrigation practice at improving crop yield.

The water management philosophy of irrigation efficiency is commonly broken out into three parts: storage efficiency (Es), conveyance efficiency (Ec), and application efficiency (Ea). The overall efficiency of a system is the product of these three parts. Most studies focus on Ea exclusively, as the other two variables are very site-specific. Nonetheless, Es and Ec can be significant in many situations (e.g., irrigation ponds, open irrigation supply ditches, etc.).

The FIRM operates solely within the Ea term, which is considered to be the product of the "potential" irrigation application efficiency (Ep) and a management factor (Fm). The FIRM is essentially a rational approach for computing Fm based on a number of factors, such as:

- Flow measurement practices and irrigation scheduling
- Maintenance of the system (e.g., replacing sprinkler heads regularly)
- Experience and skill of the operator
- Site and system conditions (e.g., application uniformity, pressure variations, etc.)

For the current study and phase of the CFACT, values for these items were combined into the three O&M classes: deferred, reactive, and proactive. The costs associated with new system installation and the three classes of O&M are taken directly from the literature review effort. Further refinement of new system cost estimates, and other associated crop-specific costs (e.g., fertigation, chemigation, etc.), is planned following the development of the Ag land geodatabase and irrigation estimates task. These refinements, in conjunction with preliminary CFACT runs, will identify the crops and/or irrigation systems with the greatest water conservation potential. Considering the extensive variety of crops that are grown within the study area, this procedure will allow for a rational expenditure of effort on the systems and crops that will have the greatest impact on the CFACT results.

Ag Land Geodatabase and Crop Irrigation Requirements

The Ag land geodatabase and associated irrigation estimates are being developed concurrently with the base assumptions for the CFACT. While it was initially envisioned that actual crop water usage data could be used (where it was available), it was determined the problems previously discussed for converting this data on a per-acre basis (and then using rainfall data to speculate on the 1995 withdrawals) would lead to errors.

In addition, these errors would severely limit the effectiveness of the CFACT to be run on a large scale because the model would undoubtedly focus itself on the sites where the per-acre irrigation is obviously too high. As an example of this, take the following hypothetical situation:

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Farm A is 10 acres and uses approximately 15 in. of water per year for irrigation. However, for one of many potential reasons discussed previously, the EN50 data for this site suggests that it is using 200 in. per year. In the CFACT analysis, this site will almost always be selected (unless a tedious and careful effort is made to specifically exclude it) because the potential gain in water conservation will be based on the 200-in.-per-year estimate, but the cost for this gain would be based on a 10-acre site.

For now, the development of farm-level irrigation estimates for the project will rely on crop irrigation requirements modeling using the AFSIRS model. However, this approach will also have its own limitations and several generalizations will need to be made. These limitations and generalizations include, but are not limited to:

- The variety of crops grown in the study area vastly exceeds the crop types supported by the model. Therefore, crops will need to be generalized into AFSIRS crop categories. However, it is possible to use custom crop parameters (crop growth coefficients, root depths, etc.) and this may be utilized for crops with significant acreage.
- There is no set planting and harvesting date for any given annual crop. The decision of when to plant and harvest is a very complicated matter as it involves: weather forecasting; the ability to freeze, protect, or mitigate crop heat stress; and market factors. Annual crop-growing seasons will be taken from the literature and to the extent possible, by reviewing the EN50 data.
- The AFSIRS does not estimate crop establishment, freeze protection, fertigation, and other necessary Ag water uses that would ideally be captured by actual water use data. To mitigate these issues, the simulated crop requirements will be compared to the EN50 data to the extent possible. Freeze protection use could potentially be accounted for through analysis of weather information.
- Other necessary simplifications made by the AFSIRS model include limited weather monitoring network and periods of record and soil types. The AFSIRS model uses a statewide version of soil types to determine the available water capacity (AWC) of a given soil, whereas the NRCS soil surveys are conducted on a county level and AWC calculations may vary slightly from county to county.

Example Case Study: Putnam County

As mentioned previously, this project is an ongoing effort as data and input continue to be collected. However, to test out the planned project methodology as described in the previous section and shown in Figure 2, a test case was carried out for Putnam County. This county was selected mainly because there was sufficient MIL data available for characterization of the various irrigation practices and crops.

Table 2 provides a breakdown of the predominant irrigation type for the irrigated crops grown in Putnam County and their AFSIRS-generated net crop water requirement. This information was derived from the District's 2010 irrigated areas layer and consists of 568 irrigated polygons and 260 nonirrigated polygons. Only the irrigated polygons were used as input to the CFACT.

A total of 24 AFSIRS simulations were executed, one for each of the crop types listed in Table 2. The associated assumptions used for the AFSIRS are:

- One soil type was used for each crop. The soil type selected was the predominant soil type for each crop in the list. Ultimately, the predominant soil type for each farm will be computed and used in the model.
- The climate database used was from Jacksonville, which was developed when the AFSIRS model was originally released in 1990. While more up-to-date climate databases could have been utilized through the District's GWRAPPS, or GIS-based water resources and agricultural permitting and planning system (SJRWMD, 2013), this approach would have been unnecessarily tedious for this demonstration exercise. This input parameter will be refined at a later time by using the nearest database for each farm.
- The model was run in net irrigation mode to eliminate the default irrigation efficiency. The CFACT internally computes gross irrigation requirements based on the initial and optimized irrigation efficiency.
- A uniform depth to a water table of 3 ft was used and the "normal" irrigation mode was selected. This irrigation option tells the model to internally calculate and add the exact amount of water needed to replenish the AWC in the root zone.

Table 2. Summary of Putnam County Irrigated Areas

Crop Type	Area (ac)	Percent	Predominant Irrigation System	AFSIRS Net Crop Water Requirement (In.)[1]
Potatoes	4,583.9	39.8	Pipeline Seepage (99.7 percent)	6.7
Asparagus Fern	1,315.3	11.4	Impact Sprinkler (100 percent)	23.6
Pasture	1,289.8	11.2	None (97.1 percent); Pipeline Seepage (2 percent)	22.5
Hay	761.9	6.6	Linear Move (74.6 percent); None (25.4 percent)	17.8
Greens	409.3	3.6	Pipeline Seepage (99.8 percent)	3.4
Container Nursery	393.1	3.4	Micro Drip (64.1 percent); Micro Jet (22.8 percent)	25
Sorghum	360.8	3.1	Pipeline Seepage (100 percent)	9.7
Cabbage	340.7	3.0	Pipeline Seepage (100 percent)	3.5
Leatherleaf	315.5	2.7	Impact Sprinkler (100 percent)	23.1
Citrus	313.3	2.7	Micro Jet (92.8 percent)	9.1
Aspidistra	276.5	2.4	Impact Sprinkler (100 percent)	23.4
Sod	255.8	2.2	Pipeline Seepage (100 percent)	21.1
Broccoli	177.8	1.5	Pipeline Seepage (100 percent)	3.0
Pecans	169.2	1.5	Micro Drip (96.2 percent)	5.9
Blueberries	150.7	1.3	Impact Sprinkler (100 percent)	19.7
Field Nursery	106.9	0.9	Impact Sprinkler (80.1 percent)	24.8
Spinach	91.0	0.8	Pipeline Seepage (100 percent)	1.6
Pittosporum	62.2	0.5	Impact Sprinkler (96.6 percent)	35.6
Grapes	58.8	0.5	Micro Drip (94.7 percent)	5
Corn	33.7	0.3	Pipeline Seepage (100 percent)	8.4
Onions	31.1	0.3	Pipeline Seepage (94 percent)	5
Mixed Vegetables	22.0	0.2	Pipeline Seepage (90.7 percent)	2
Liriope	5.5	0.0	Impact Sprinkler (100 percent)	26.8
Greenhouse Nursery	1.5	0.0	Sprayhead Sprinklers (100 percent)	26.9
Totals	11,526.1	100		

[1]See discussion on assumptions used in AFSIRS modeling

The Putnam County dataset was simulated in the CFACT model by aggregating the parcel data by irrigation type and crop. This simplification was made to reduce run times so that several approaches to the data could be tested out. For example, the model can be used to maximize water savings given a fixed budget or minimize the cost to achieve a particular water savings goal.

Figure 3 shows a graph of the results when a range of fixed budgets were assumed to determine the potential water savings. It is important to bear in mind these results are preliminary and will be refined as the project continues. For fixed budgets of $100,000 or less, the CFACT is limited by the cost of the potential water savings practices. The water saved per dollar spent substantially improves for fixed budgets ranging between $100,000 and $750,000 because the most effective water saving practices are selected. Beyond this, water savings flattens out until a fixed budget of about $2 million is used, indicating that the most costly water savings practices are utilized. Water savings ultimately reaches its limit at a fixed budget of about $10 million.

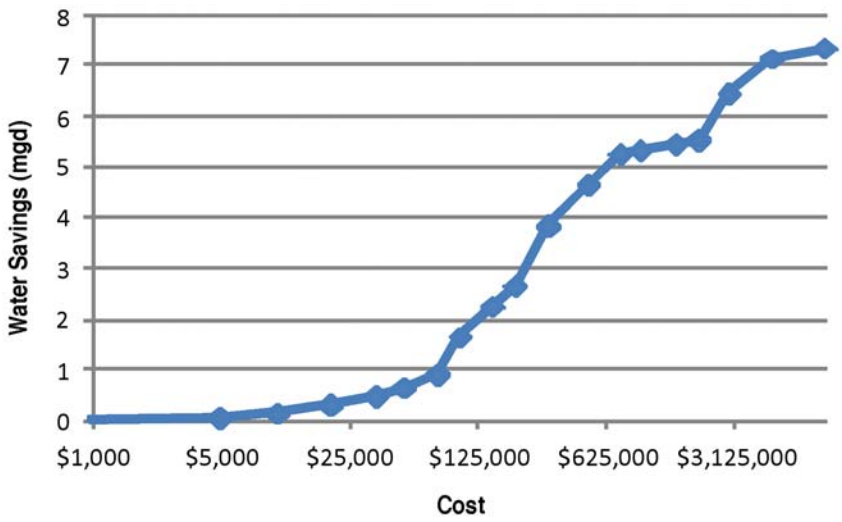

Figure 3. Cost-Water Savings for CFACT Demonstration Simulation

Summary and Conclusions

The current discussion summarizes the preliminary results of what will be an ongoing effort. Data will continue to be collected (e.g., consumptive/water use data from other water management districts and MIL data for additional farms) and synthesized into the CFACT and Ag land geodatabase. The literature review will continue to be expanded to help refine the assumptions used by the CFACT. Most importantly, collaboration with producers, FDACS, universities, industry experts, and District staff will provide additional input and an overall reality check.

With improved integration of the input Ag lands database with site-specific information, such as water source information (e.g., groundwater vs. surface water supply, pump type(s), and total dynamic head for pumping systems), topography, crop-specific fertilization and chemigation practices, the CFACT could ultimately be refined to the site level. Much of this information, however, would be collected by on-site irrigation audits, and this level of effort is beyond the current scope. Refinements to the CFACT will go hand-in-hand with improvements to the Ag lands geodatabase and irrigation estimates.

In addition, future enhancements to the CFACT will include a more comprehensive array of water saving strategies and BMPs. The current work is limited to the more global types of water savings strategies, but it is envisioned that BMPs specific to certain types of crops and irrigation systems can be incorporated into the model (e.g., low energy precise application for center pivots, tillage practices, etc.).

The results presented here demonstrate that the CFACT model and Ag lands geodatabase have great potential to be a useful planning-level conservation tool. Following the law of diminishing returns, the CFACT can be used to show the relationship between water savings and costs for implementation. The utility of this model will be greatly enhanced once the entire study area domain is completed. While it is speculated that the CFACT model will have difficulty running the entire Ag lands geodatabase at once, running the model on a subset of the data (e.g., by county, region, irrigation type, or crop type) will be a fairly simple task. The flexible nature of the input assumptions will facilitate future refinements and customized analyses. In addition to supporting regional hydrologic modeling efforts, the Ag lands geodatabase synthesizes a wealth of information that can be used in a wide variety of ways.

Regardless of the accuracy of the CFACT model and its utility to conservation planning and potentially other disciplines, the implementation of water conservation within the Ag sector will largely remain a matter of aligning incentives. Unlike public water supply utilities, Ag producers are not faced with an ever-expanding demand for water. Their decision to expand their acreage and increase their water demands is a business decision. When the decision to expand is made and increased water withdrawals are necessary, water supplies become directly limited, or a monetary value is assigned to water, Ag producers will be more engaged in conservation practices and alternative water supply strategies. This notion is supported by the implementation of irrigation water conservation practices in Texas and other western states.

When proper incentives are provided, the sheer ingenuity of the Ag industry in Florida will once again accelerate the adoption of conservation practices and lead the way in future innovations. Such was the case with the movement from open-ditch seepage irrigation systems to semi-closed seepage irrigation systems, and from overhead sprinklers to microspray irrigation systems in potatoes and citrus, respectively. There is simply no substitute for the intimate knowledge and experience that farmers have of their land and operations.

References

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