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METHODOLOGY FOR ESTIMATING HISTORICAL AGRICULTURAL GROUNDWATER USE IN THE CENTRAL FLORIDA COORDINATION AREA (CFCA) 1957–2010

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By

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and
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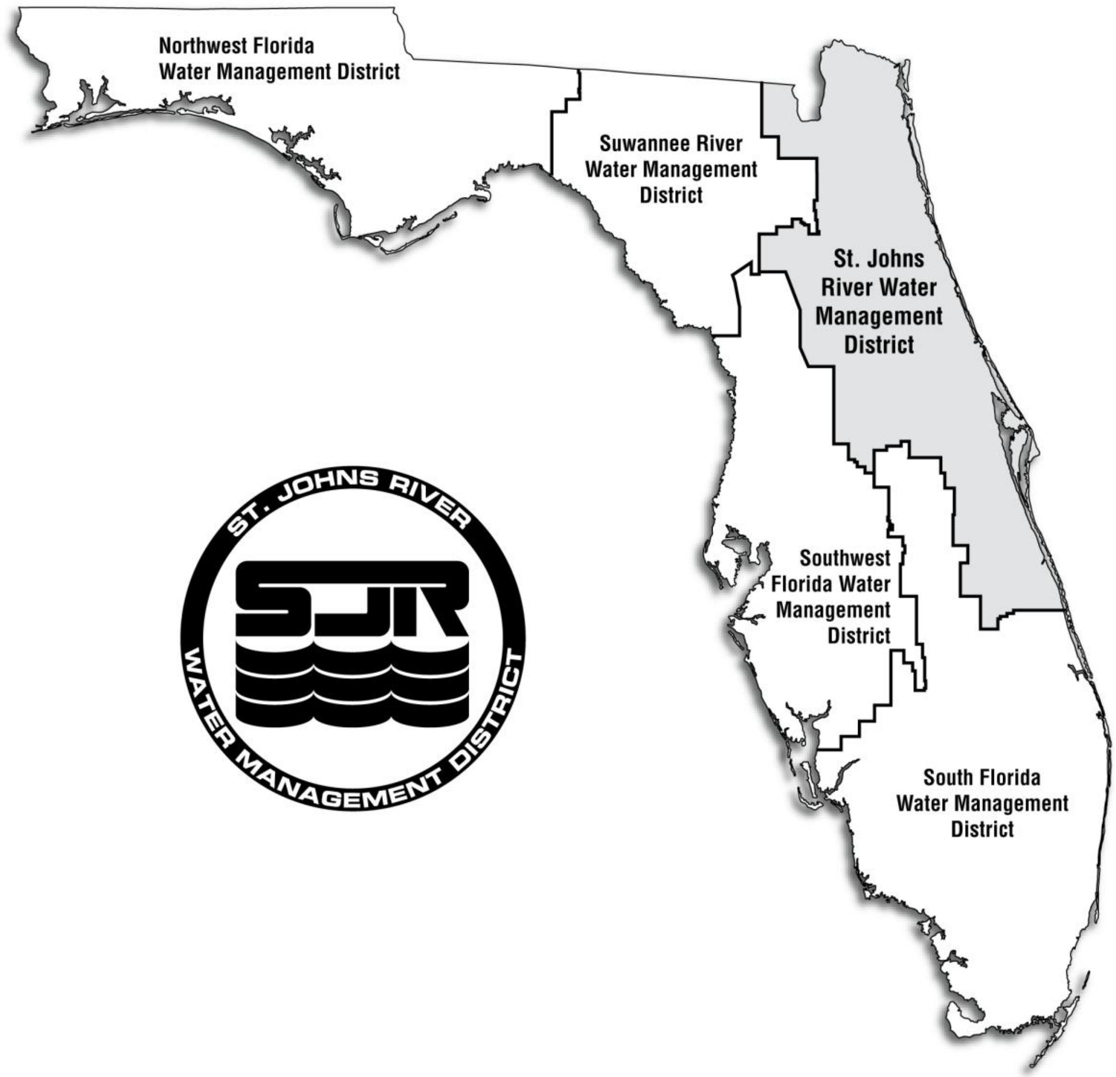
Palatka, Fla.
2012



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EXECUTIVE SUMMARY

The St. Johns River Water Management District (SJRWMD) prepared this document to present the data and methods used to estimate, allocate, and distribute historical groundwater use for spatial non-citrus agriculture (ag), citrus, and golf course uses for the Central Florida Coordination Area (CFCA). Because of the uncertainty associated with irrigation practices for improved pasturelands within the CFCA, it is not addressed as part of this study. The CFCA includes five counties (Lake, Orange, Osceola, Polk, and Seminole) in three water management districts (WMDs) — St. Johns River (SJRWMD), South West Florida (SWFWMD), and South Florida (SFWMD). The final data set is in feature class format (ArcGIS 9.3) with monthly time-series groundwater use data (units in average gallons of groundwater per day, by month) from 1957–2010 (although using all years may not be appropriate in all cases). This data is most appropriately used when considering semi-regional historical annual groundwater use distribution, and not historical agricultural acreages. Previous to this study, there were not detailed, reliable historical groundwater use estimates in the CFCA. The final data set generated in this project reasonably approximates known groundwater use trends in the region during this time period, including the shift of citrus production southward from Lake and Orange counties into Polk County following heavy freezes, and the displacement of agriculture during periods of urban infrastructure expansion.

The toolboxes and models for this project are created within ArcGIS 9.3, using ModelBuilder. The data used consisted of spatial and water use data from multiple sources. Total water use estimates are compiled by the WMDs and U.S. Geological Survey (USGS) and then groundwater use data are interpolated and extrapolated based on acreage estimates from best available sources (usually National Agricultural Statistics Service [NASS], for citrus; USGS, and WMDs). This provides the best groundwater use estimates for a given county (Lake, Orange, Osceola, Polk, or Seminole) and land cover (citrus, non-citrus agriculture, or golf). Polygons representing historical land cover are generated in custom ArcGIS models, using the best available geographic information system (GIS) land use/land cover data from NASS, USGS, WMDs, and Florida Geographic Data Library (FGDL). Although the total acreage of these polygons may not equal the best acreage estimates from other sources (particularly NASS citrus-acreage estimates), they are assumed to be accurately distributed proportionately. Therefore, the acreage estimates generated in these models are not necessarily accurate, but the proportional distribution is assumed to be accurate. The groundwater use estimates are distributed among the polygons based on proportional size. The monthly distribution of water is determined using an unweighted average of common crop types and/or irrigation regimes. Although the exact polygon acreage of the GIS data is not the same as the acreages used to generate the groundwater use estimates, the final distribution of groundwater use (on a semi-regional, or maybe even countywide scale) is assumed to be accurate. Therefore, only the groundwater use estimates generated from these models are considered to be accurate (on a semi-regional scale), not the polygon acreages. See

Assumptions (Appendix A) for further explanation of assumptions present in these models.

Decadal trends across all agricultural groundwater use were found to increase from an annual average of approximately 146 million gallons per day (mgd) in the 1950s to a maximum annual average of 317 mgd during the 1980s. From the 1980s to the present, total agricultural water use has declined to an average annual of approximately 246 mgd for the most recent years beginning in 2000. Citrus is the largest agricultural water use, followed by a similar pattern beginning in 1957, with an estimated annual average groundwater use of approximately 35 mgd and an increase to a maximum annual average of just under 200 mgd by 1978. Since 1978, citrus has remained within an annual average range of 160 mgd to 180 mgd, pending climatic conditions. Other non-citrus agricultural crops also followed a similar pattern, beginning in 1957 with an average annual groundwater use of approximately 25 mgd, increasing to approximately 80 mgd by 1985 and then declining to a annual average in the most current years of approximately 70 mgd. Estimated groundwater use for golf course irrigation has been steadily increasing from an estimated annual average of 10.9 mgd in 1980, which is the first year of available data for all counties, and approaching 20 mgd during the most recent years.

The final data set will be incorporated into local and spatially interpolated Artificial Neural Network (ANN) models developed by USGS, a work product of the Central Florida Water Initiative (CFWI), a collaborative water supply planning process for the CFCA.

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INTRODUCTION

The Central Florida Coordination Area (CFCA) Historical Agricultural Groundwater Use Estimation Project is part of a larger effort known as the CFCA Data Mining Project that is cooperatively funded by the St. Johns River, Southwest Florida, and South Florida water management districts, with the U.S. Geological Survey (USGS). The CFCA consists of all or part of Lake, Orange, Seminole, Polk, and Osceola counties. The overall objective of the project is to evaluate the degree to which natural and anthropogenic stresses influence the groundwater flow system. The Data Mining Project seeks to leverage existing data to inform a self-teaching model that will be used to refine a USGS MODFLOW model for this same area.

In a physically based, numerical groundwater flow model such as MODFLOW, the geometry and physical nature of the hydrogeologic system must be defined over a large spatial area so that a simulation model may be developed to replicate observed water levels. The Data Mining Project utilizes a self-teaching modeling approach known as an Artificial Neural Network (ANN). In general terms, an ANN assumes that the physics of the hydrogeologic system are represented by the relationships that exist between a set of inputs (e.g., rainfall, evapotranspiration, and groundwater pumping) and corresponding outputs or responses at given observation locations (e.g., groundwater levels, lake water levels, and spring flows). ANNs become more robust with longer time-series information.

As with any groundwater modeling project, water use is a critical component. Unlike public water supply, historical records of agricultural water use are, at best, only rough estimates. In reviewing historical information, reported estimates of water use for agriculture can vary significantly, depending on data source, and are usually aggregated by county. In the CFCA, the primary agricultural commodity is citrus. In addition, other agriculture such as vegetables (i.e., melons, carrots, corn, or cabbage) plus ornamentals and tree nurseries, and golf/turf grass contributes to the overall regional water use. It is also recognized that potential exists for improved pasturelands to be irrigated for cattle production in the study area; however, because of the uncertainty associated with pasture irrigation practice and the continuity of irrigation for this purpose, estimates were not made as part of this study. In order to develop the databases needed to build the ANN models, a method for spatially, and historically, estimating the location of crop acreages and the associated groundwater use was developed.

METHODS

ESTIMATING HISTORICAL AGRICULTURE ACREAGES

GIS Data Sources for Historical Agriculture Acreage Delineation

The following data sources were used in the creation of historical acreages, moving backward through time. Although source institutions may be the same, this spatial geographic information system (GIS) data is independent of the data used in the estimation of historical groundwater use. All base data sets were obtained from St. Johns River Water Management District (SJRWMD) servers, except as noted (Table 1). For more information on acceptable data sources, see Appendix B. Throughout this project, unless otherwise specified, "ag," "agriculture," or "agricultural" refers to non-citrus agriculture, because citrus is handled separately, and "total agriculture" refers to citrus and non-citrus agriculture combined.

Table 2 describes the data source and selection criteria (using Visual Basic in ArcGIS 9.3) used in the estimation of historical agricultural, citrus, and golf course acreages. Generally, the physical area covered by each data set is the same as the range of influence of the responsible institution. Relevant years for each data set are noted, as well as notes and coverage differences. The data selection criteria are recorded as they are used in the ArcGIS models. Depending on the data source, "FLUCCS," "FLUCCSCODE," "LCCODE," and "LUCODE" are often identical, and reference the Florida Land Use, Cover and Forms Classification System (FLUCCS), as developed by the Florida Department of Transportation (FDOT). Although the specifics can be obtained directly from the source, the general categorization of relevant FLUCCS selections in this project includes the following:

- For agriculture, 2139<FLUCCS< 2199 generally refers to row crops, field crops, and sugar cane, while 2399<FLUCCS<2499 generally refers to nurseries and vineyards, tree nurseries, sod farms, and ornamentals.
- For citrus, 2199< FLUCCS < 2239 refers to tree crops, citrus groves, fruit orchards, and other groves.
- For golf courses, 1820 is the specific FLUCCS code for golf courses.

Table 3 describes the data sources that were either not used, did not exist, or were rejected from this project. The reasons are given in the table. Often the reason for rejection was that a better data set existed. For an example, compare Table 2 to Table 3, by the field "relevant year," and notice that most of the time the unused data set has been replaced by another for a given year. See Appendixes C and D for a detailed explanation of the inner workings of the ArcGIS9.3 ModelBuilder models that created spatial portion of the final product, as well as the groundwater use estimates and how they were joined to the spatial data.

Table 1. GIS base data set utilized in historical acreage delineation for all water use types

GIS base data set used in historical acreage delineation
lu_swfwmd_2008
GISLIB.LULC_OTHER_2006_SWFWMD*
WSMLIB.SJRWMD_AG_2005
GISLIB.LULC_OTHER_2005_SWFWMD (aka GISLIB.LULC_OTHER_2005)
NASSactive_10**
NASSinactive_10**
GISLIB.LULC_OTHER_2004_SFWMD (aka GISLIB.LULC_OTHER_2004)***
GISLIB.LULC_2004
fwc_03_sjr (aka fwc03)****
lu0035, lu0048, lu0049, lu0053, lu0059*****
GISLIB.LULC_1995_sjr (aka GISLIB.LULC_1995)
GISLIB.LULC_OTHER_1995_SWFWMD*
GISLIB.LULC_OTHER_1995_SFWMD***
gap_lcov35, gap_lcov48, gap_lcov49, gap_lcov53, gap_lcov59*****
lu9035, lu9048, lu9049, lu9053, lu9059*****
Land Cover 1985-1989 FWC raster (aka Land Cover 1985-1989)****
usgslu_1974******
All data obtained from SJRWMD, except as noted:
*obtained from SWFWMD at *www.swfwmd.com*, maintained in the SJRWMD GIS database.
**obtained from NASS, Florida Branch (FASS).
***obtained from SFWMD at *www.sfwmd.gov*, maintained in the SJRWMD GIS database.
****obtained from FGDL at *www.FGDL.org*, originally from Florida Fish and Wildlife Conservation Commission (FWC).
*****obtained from FGDL at *www.FGDL.org*.
******obtained from USGS

Table 2. Base GIS data layer and data sources used in delineation of historical acreages

Data used in the delineation of historical acreages						
Data Source	**Data name 1 (original GIS layer name)**	**Relevant Year**	**Data name 2 and/or notes**	**Ag data selection criteria**	**Citrus data selection criteria**	**Golf data selection criteria**
NASS	NASSactive_10	2010	citrus only	n/a	All	n/a
NASS	NASSinactive_10	2009-2005	citrus only	n/a	2009-2005, individually	n/a
SWFWMD	lu_swfwmd_2008	2008	lu_swfwmd_2008	("FLUCCS" > 2139 AND "FLUCCS" < 2199) OR ("FLUCCS" > 2399 AND "FLUCCS" < 2499)	"FLUCCS" = 2200	"FLUCCS" = 1820
SWFWMD	GISLIB.LULC_OTHER_2006_SWFWMD	2006	GISLIB.LULC_OTHER_2006_SWFWMD	("FLUCCSCODE" > 2139 AND "FLUCCSCODE" < 2199) OR ("FLUCCSCODE" > 2399 AND "FLUCCSCODE" < 2499)	"FLUCCSCODE" = 2200	"FLUCCSCODE" = 1820
SJRWMD	WSMLIB.SJRWMD_AG_2005	2005	WSMLIB.SJRWMD_AG_2005	"BASELAYERS" = 'Field crops' OR "BASELAYERS" = 'Floriculture' OR "BASELAYERS" = 'Hammock ferns' OR "BASELAYERS" = 'Mixed crops' OR "BASELAYERS" = 'Nurseries and vineyards' OR "BASELAYERS" = 'Nursery' OR "BASELAYERS" = 'Ornamentals' OR "BASELAYERS" = 'Row crops' OR "BASELAYERS" = 'Shade ferns' OR "BASELAYERS" = 'Sod' OR "BASELAYERS" = 'Tree Nursery' OR "BASELAYERS" = 'Tree crops'	"BASELAYERS" = 'Citrus groves'	n/a
SWFWMD	GISLIB.LULC_OTHER_2005_SWFWMD	2005	GISLIB.LULC_OTHER_2005	("FLUCCSCODE" > 2139 AND "FLUCCSCODE" < 2199) OR ("FLUCCSCODE" > 2399 AND "FLUCCSCODE" < 2499)	"FLUCCSCODE" = 2200	"FLUCCSCODE" = 1820

SFWMD	GISLIB.LULC_OTHER_2004_SFWMD	2004	GISLIB.LULC_OTHER_2004	("LCCODE" > 2139 AND "LCCODE" < 2199) OR ("LCCODE" > 2399 AND "LCCODE" < 2499)	"LCCODE" > 2199 AND "LCCODE" < 2239	"LCCODE" = 1820
SJRWMD	GISLIB.LULC_2004	2004	GISLIB.LULC_2004	("LCCODE" > 2139 AND "LCCODE" < 2199) OR ("LCCODE" > 2399 AND "LCCODE" < 2499)	"LCCODE" > 2199 AND "LCCODE" < 2239	"LCCODE" = 1820
FWC	fwc_03_sjr	2003	fwc_03_sjr, only on SJRWMD land	"VALUE" = 35 OR "VALUE" = 36	"VALUE" = 34	n/a
FGDL	lake1999_lu0035, orange1999_lu0048, osceola1999_lu0049, polk1999_lu0053, seminole1999_lu0059	1999	lu0035, lu0048, lu0049, lu0053, lu0059	("FLUCCS" > 2139 AND "FLUCCS" < 2199) OR ("FLUCCS" > 2399 AND "FLUCCS" < 2499)	"FLUCCS" > 2199 AND "FLUCCS" < 2239	"FLUCCS" = 1820
SJRWMD	GISLIB.LULC_1995 -sjr	1995	GISLIB.LULC_1995	("LUCODE" > 2139 AND "LUCODE" < 2199) OR ("LUCODE" > 2399 AND "LUCODE" < 2499)	"LUCODE" > 2199 AND "LUCODE" < 2239	"LUCODE" = 1820
SWFWMD	GISLIB.LULC_OTHER_1995_SWFWMD	1995	GISLIB.LULC_OTHER_1995_SWFWMD	("FLUCCSCODE" > 2139 AND "FLUCCSCODE" < 2199) OR ("FLUCCSCODE" > 2399 AND "FLUCCSCODE" < 2499)	"FLUCCSCODE" > 2199 AND "FLUCCSCODE" < 2239	n/a
SFWMD	GISLIB.LULC_OTHER_1995_SFWMD	1995	GISLIB.LULC_OTHER_1995_SFWMD	("LUCODE" > 2139 AND "LUCODE" < 2199) OR ("LUCODE" > 2399 AND "LUCODE" < 2499)	"LUCODE" > 2199 AND "LUCODE" < 2239	"LUCODE" = 1820
FGDL	lake_1993_gap_lcov35, orange_1993_gap_lcov48, osceola_1993_gap_lcov49, polk_1993_gap_l	1993	gap_lcov35, gap_lcov48, gap_lcov49, gap_lcov53, gap_lcov59	"CLASS_NAMES" = 'Agriculture' OR "CLASS_NAMES" = 'Agriculture/Groves/Ornamental'	"CLASS_NAMES" = 'Agriculture/Groves/Ornamental'	n/a

	cov53, seminole_1993_gap_lcov59					
FGDL	lake1990_lu9035, orange1990_lu9048, osceola1990_lu9049, polk1990_lu9053, seminole1990_lu9059	1990	lu9035, lu9048, lu9049, lu9053, lu9059	("FLUCCS" > 2139 AND "FLUCCS" < 2199) OR ("FLUCCS" > 2399 AND "FLUCCS" < 2499)	"FLUCCS" > 2199 AND "FLUCCS" < 2239	"FLUCCS" = 1820
FWC	Land Cover 1985-1989 FWC raster	1985	Okay for citrus only when constrained by later data (i.e. usgslu_1974)	"VALUE" = 19	"VALUE" = 19	n/a
USGS	usgslu_1974	1974	used primarily to constrain raster coverages. and for final in each county	"LU_CODE" = 2100 OR "LU_CODE" = 2400	"LU_CODE" = 2200	n/a

DATA SOURCES:
FGDL = Florida Geographic Data Library
FWC = Florida Fish and Wildlife Conservation Commission
NASS = National Agricultural Statistical Service, Florida Branch
SFWMD = South Florida Water Management District
SJRWMD = St. Johns River Water Management District
SWFWMD = Southwest Florida Water Management District
USGS = U.S. Geological Survey

Table 3. Base GIS data not used in this project

Explanation of unused data			
Data Source	**Data Source/Original GIS layer**	**Relevant Year**	**Explanation**
SJRWMD	WSMLIB.SJRWMD_2005	2005	This data set does not exist. Next best is GISLIB.LULC_2004.
SJRWMD	GISLIB.LULC_2000 -sjr	1999	same as lu00 data
SFWMD	lscndclu99_polygon	1999	same as lu00 data
SJRWMD	WSMLIB.SJRWMD_1995	1995	Coverage worse quality than GISLIB.LULC_1995-sjr.
SFWMD	lscndclu95_POLYGON	1995	same as GISLIB.LULC_OTHER_1995_SFWMD
SJRWMD	GISLIB.LULC_1990 -sjr	1990	Uncertain quality
SFWMD	lscndclu88_POLYGON	1988	Uncertain quality
SJRWMD	lulc19881990x	1988	Uncertain quality
SJRWMD	Land Use 1984 (partial coverage)	1984	Uncertain quality; not used or needed
USGS	fllu_1977	1977	Could be used to constrain raster coverages
SJRWMD	Land Use 1973	1973	Could be used to constrain raster coverages
DATA SOURCES: SFWMD = South Florida Water Management District SJRWMD = St. Johns River Water Management District USGS = U.S. Geological Survey			

Delineating Historical Agriculture Acreage

Using the most current Land Use/Land Cover (LULC) GIS data for a given county and water use type, the appropriate polygons were extracted using the selection criteria in Table 2. These polygons represent the best knowledge of historical areas covered by a specific water use type for the time period that each data set is relevant. The polygons from all data sets were then aggregated, while being careful to maintain the integrity of the time period for which each polygon is relevant.

In all instances, a conservative paradigm was adopted in this project, to best avoid the occurrence of false positives in spatial groundwater use signatures in the final product. The final product is the final data set(s) created by the processes described and executed in this project. Since the final product is concerned with the regional or semi-regional distribution of historical groundwater use, the exact location and quantity of acreages is not as important if the regional and proportional distributions of historical acreages are accurate. So, for instance, a false positive could be caused by an overly specific or unjustified assumption or process that affects the regional or proportional distribution of historical acreages, which then affects the accuracy of the spatial groundwater use estimates in the final product.

Moving backward through time from the present, historical acreages were compiled with other historical acreages to create complete historical acreage estimates for each county. In the case of agriculture and citrus, acreages are assumed to have been present from when they first appear in LULC data and in all earlier years (backwards in time), throughout the entire time period addressed in this project (Figure 1). Therefore, if a certain area is designated as citrus in the year 2000 LULC data, but not in the year 2005 LULC data, it is assumed that that particular area was not in citrus cultivation for 2001 through 2010, but was in citrus cultivation from year 2000 through 1957. Conversely, golf courses are assumed to be present from the time they first appear in the LULC data until present-day.

There was incomplete GIS data for most of the time span encompassed by this project. In those instances, it was necessary to make assumptions about historical acreages on either end of the temporal scale of this project. The oldest LULC data depicts agricultural coverage from 1974. These acreages are assumed to have been present from 1957 to 1974. This is a large time period to span, but it is the proportional and regional distributions that this project is concerned with, not the absolute acreages or individual polygons. Closer to year 2010, often the best data for a county, or a portion of a county, comes from year 2008, 2006, or 2005 LULC GIS data. In these cases, the nearest available data for an area was copied forward, over intervening years, to 2010. Although this produces an acreage estimate that is likely overestimated for years closer to the present (due to the continuing decline of total agricultural impact in Florida), it is still a better estimate than assuming the alternative of “zero acreage” from 2010 to the most current LULC data. In addition, as acreages and groundwater use are estimated back through time, the uncertainty associated with each grows with greater distance from the nearest discrete data point.

Public lands that were present at a data set's relevant time period were also masked out, because agriculture or citrus is not generally found on publicly protected lands that are managed by the state. "Masking out" is a geospatial data handling method of removing the areas or data discussed from consideration in the final analysis. Masking essentially deletes the areas specified from the final data set for the appropriate time period. Public lands were determined to be appropriate areas from Florida Managed Areas (FLMA), the Florida Natural Areas Inventory (FNAI), and Florida Forever (FF) lands. A "year established" for each parcel was not always possible to obtain. When one existed without a "year established," that parcel was masked out from that year forward to 2010. When no year established was available, the parcel was assumed to have been protected for the duration of this project, meaning that those lands were excluded from the final product.

For ag and citrus, polygons that were less than one-quarter acre (0.25 acre) were not retained, as this was too small an area to be considered relevant to this historical estimation. For golf, only polygons larger than one-half acre (0.5 acre) were retained. It is likely that these areas represented "slivers" or negligible errors in estimation from original LULC data delineation or data processing. The reason golf courses have a larger margin is that they are very easy to originally delineate in imagery (via the FLUCCS coding process), and golf course areas are not very likely to grow by an area less than one-half acre between two time periods. Regardless of water use type, these small areas did not contribute significantly to the overall spatial distribution of groundwater use in the final product. Additionally, the computations involved in these models would create very small groundwater use estimates for these sliver polygons, which had the potential to distort the final product. This is why they were removed in the fashion described above.

The GIS data set "usgs_1974" designates basic areas as agriculture, urban, or forest and provides a pre-freeze guide for these areas as of 1974. "Pre-freeze," refers to the impact freezes of the early 1980s that severely affected the citrus industry in Florida. (Information accessed online at *http://www.flcitrusmutual.com/industry-issues/weather/freeze_timeline.aspx*). In general, the usgslu_1974 data set was used to constrain all raster data, after it was selected for the appropriate water use type and converted to vector data. This is due to the nature of the raster data sets, which involve extensive coverages that are not 100% accurate. Three raster data sets were used in this project: a Florida Fish and Wildlife Conservation Commission (FWC) data set for 2003, a Florida Geographic Data Library (FGDL) data set for 1993, and a LULC data set for 1985. Since the purpose of this project is to determine regional or semi-regional groundwater use distribution, these raster data sets, if left unconstrained, would have significantly diluted the spatial signal present in the data. For the purposes of this project, it is assumed that ag and citrus present in earlier time periods have been present in all other past time periods, and that ag and citrus were more prevalent in more historical times. The corollary presents itself that past time periods contain all the possible acreage locations of all more current data sets. This is the reason that raster data sets were constrained by the USGS 1974 data set: to preserve regional and semi-regional proportional distribution and data signal clarity.

The time period relevancy of each polygon was tracked by giving it a unique identifying field called "FID1," which is equal to the year the polygon appeared in GIS data suffixed by 4 zeros ("0000") added to the FID field (which is an unique identifier within the ArcGIS software; an internal tracking field). So for instance, if there were only five polygons for year 1989, they would have FID1 fields 19890001, 19890002, 19890003, 19890004, and 19890005. This field will remain unique as long as the number of polygons in a given year does not exceed 9999, which did not occur in this project.

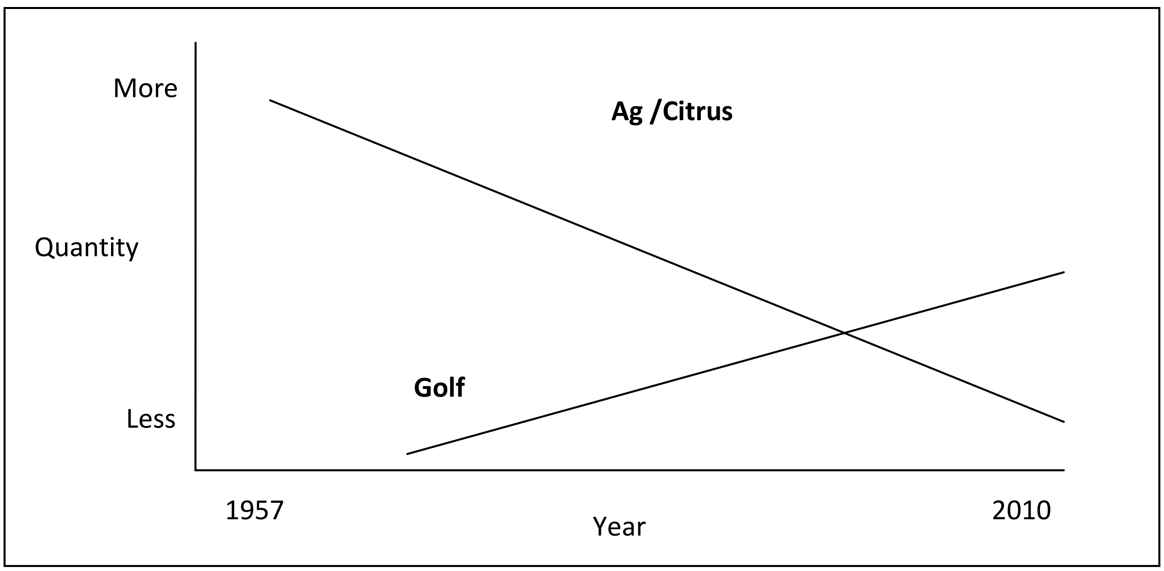

Figure 1. Theoretical quantity of water use types through time

Citrus-Specific Delineation Considerations

The Florida branch of NASS (FASS) provided current spatial citrus acreages for the SJRWMD portion of the CFCA counties (GIS data layer named "Active_10" and "Inactive_10" delineating active and inactive citrus acreages as of 2010). Whenever possible, these acreages, current for year 2010, were used as the starting point for creating historical citrus acreage estimations for each county. In counties without FASS GIS data, the nearest time period LULC data was used, typically from the responsible

WMD. When NASS GIS data are not available, other LULC data must be utilized as a starting point. Generally, citrus acreages were coded by FLUCCS codes in the 2200s. When there was a combination of FASS and other data, the next available other data was copied forward to year 2010, for the area not covered by the FASS GIS data. Consult CFCA_data_coverage_by_source.xlsx or Appendix E for a detailed description of each county's data availability. See Table 2 for detailed information on how each GIS data set had citrus selected. Moving backwards through time, the process was repeated (with the additional masking out of previous years' citrus acreages), adding citrus acreage with each interval.

Other Agricultural Crop-Specific Delineation Considerations

Agricultural acreage delineation proceeded in a very similar fashion to citrus. To prevent overlap, citrus acreages were delineated first and then erased from agricultural acreages. This was accomplished near the end of model step 1 (see Appendix C), using the citrus delineation data set as a mask. This is also why the citrus final data set was created before the ag final data set for each county.

Agricultural acreages for discrete years as provided by LULC GIS data layers, starting at present, were selected for non-citrus agriculture (Table 2). This included FLUCCS codes greater than 2139 and less than 2199 (mostly row crops or field crops); and FLUCCS codes greater than 2399 and less than 2499 (mostly sod, ornamentals, vineyards, and nurseries). Moving backwards through time, the process was repeated (with the additional masking out of previous years' agricultural acreages), adding agricultural acreage with each interval. This provided a final GIS data layer that has increasing steps of historical agricultural acreage. For a detailed description of each county's data availability, see CFCA_data_coverage_by_source.xlsx or Appendix E.

Golf Course-Specific Delineation Considerations

Although golf course delineation followed the same general framework as citrus and agriculture, there were some significant differences that required accommodation. For instance, since golf courses are built and increase in number approaching year 2010 from previous years, this data set was spatially constructed from the oldest data set first, working forwards to the most recent data set. Therefore, any golf course present in a given data set is present that year and all years forward to 2010. In contrast, agriculture and citrus data sets were built from most recent data set backwards to the most historical data set. Generally, golf courses are coded in the FLUCCS coding system as 1820. Golf courses are presumed not to overlap with public land, and to be distinct and mutually exclusive from citrus and agriculture. See Appendix E or consult CFCA_data_coverage_by_source.xlsx for a detailed description of each county's data availability.

ESTIMATING GROUNDWATER USE

Overview

Primarily using data derived from the USGS, WMDs, and NASS, groundwater use estimates were made for years 1957–2010 for agriculture and citrus, and for years ranging from 1977 to 1980 through 2010 for golf courses. National Agricultural Census (AgCensus) data was usually only used to confirm that the extrapolated and estimated groundwater use data was in an acceptable range of other estimates. Groundwater use was separated from surface water use, although total water use was occasionally used as a variable for filling missing data. Generally, linear interpolation and extrapolation were used for data filling and estimation of missing values. Occasionally, it was necessary to extrapolate historical groundwater use estimates by using exponential trend lines derived from existing or interpolated data. Ratios were also employed extensively in data filling. For instance, it was occasionally necessary to assume the ratio of groundwater use to total water use for a particular water use type (citrus, other agriculture, or golf) was constant across a limited time period; often five years or less. In these cases, the existing data (total water use) was multiplied by the ratio to fill the missing data (groundwater use).

When estimating groundwater use for years without reported data, linear extrapolation was occasionally used for years leading to 2010, and exponential extrapolation was used for years leading back to 1957. This is because a linear extrapolation will not lead as easily to over-estimation of present groundwater use, and an exponential extrapolation will tend not to under-estimate and will tend toward a more gradual decline in groundwater use going backward in time.

In some cases, there were multiple reputable data sources and data sets, or interpolated data sets, for a particular time period. Often these competing data sets tended to converge on a similar value. In these cases, the final groundwater use estimate for that time period was often calculated as the average of the available data sets. Occasionally, and as infrequently as was pragmatically possible, this averaged data set was then used to extrapolate other missing data values.

Since there was such accurate and abundant National Agricultural Statistics Service (NASS) Commercial Citrus Inventory (CCI) citrus acreage and citrus tree count data, it was often used as a type of reference when estimating both citrus and ag groundwater use. For instance, by calculating a ratio of groundwater used per NASS citrus tree when there were years with accurate groundwater use data, years without any groundwater use data could be linearly extrapolated based on multiplying that ratio by the CCI tree count data. Similarly, the ratio of agricultural groundwater use could also be approximated for years without any other data, by comparing the ratio of agricultural groundwater use to citrus groundwater use for known years, and then multiplying the ratio by citrus groundwater use for unknown years.

Since some of the citrus groundwater use was based on the CCI tree count ratio, as described above, and the extrapolated agricultural groundwater use estimates rested also upon a ratio that was derived from the CCI tree count data. This was often the only logical way to extrapolate historical agricultural groundwater use estimates.

SPECIFIC CONCERNS FOR ESTIMATING GROUNDWATER USE BY COUNTY

Each county had specific concerns that necessitated customized approaches for certain parts of the groundwater use estimation, allocation, or spatial identification parts of the project process. While not exhaustive, certain specific issues are detailed below for each county.

Lake County-Specific Concerns

In Lake County, the citrus groundwater use estimates for year 2000 through 2010 were too high, using the above-described method. In fact, using that method, the citrus groundwater use estimate was higher than the reported groundwater use for all agriculture in Lake County, according to the Annual Water Use Survey (SJRWMD) for years 2001 through 2009. Since that is impossible, a new estimate was determined by using Annual Water Use Survey (AWS) data from SJRWMD to create a representative ratio of reported citrus groundwater use to total agricultural groundwater use in the whole of Lake County. For missing citrus groundwater use data, this ratio was multiplied by reported total agricultural groundwater use values to create an estimate for citrus.

Orange County-Specific Concerns

At some point (possibly 1986), the Water Conserv II project switched the citrus along the Lake Wales ridge from groundwater to reclaimed water. This shift was not captured by this project, and was beyond the scope of this project. This represents a point for improving groundwater use estimates. In addition, historically, Lake Apopka non-citrus agriculture was eliminated in two large steps, each accounting for about half of the total agriculture surrounding the lake. See Schelske et al., 2005 (Ambio-Apopka). With more information, groundwater use estimate robustness for non-citrus agriculture could also be increased.

Osceola County-Specific Concerns

It was very difficult to estimate Osceola County groundwater use. SFWMD has very few records regarding groundwater use, and since their jurisdiction covers a significant amount of Osceola County, accuracy was impaired. Most estimates regarding groundwater use in Osceola County were created primarily using data from SJRWMD records, with assumptions that groundwater use trends were similar in other portions of the county.

Additionally, groundwater use for golf courses in Osceola County were either absent or reported at zero million gallons per day, even though land use land cover data (LULC) indicated the presence of golf courses. Golf courses did not have groundwater use estimates before 1990, so estimates of water usage from 1989–1980 were assumed to be zero. This is probably not an accurate assumption, but the lack of more specific data meant that a non-zero groundwater use estimate could not be made accurately.

Polk County-Specific Concerns

SWFWMD's records of reported pumping facilitated the estimation of groundwater for that portion of Polk County. However, the portion of Polk County in SFWMD had fewer data points from which to fill missing data. Additionally, the change in WMD boundaries that occurred in 2003 was taken into account when considering changes in groundwater use and the spatial water use distribution.

Seminole County-Specific Concerns

Seminole County is entirely within SJRWMD. Records of groundwater use data derived from the SJRWMD Annual Water Use Surveys (AWS) for 1977–2005, provide a very good estimate of groundwater use. In fact, because Seminole County is entirely within the jurisdiction of one WMD, with good water use estimates, it was comparatively easy to estimate groundwater use for each water use type.

Data Sources

National Agricultural Statistics Service Acreage Data

The National Agricultural Statistics Service (NASS) Commercial Citrus Inventory (CCI) are taken to be the best citrus acreage estimates for each county, and were used as a guideline in developing the historical citrus polygons. The NASS CCIs are not spatial or GIS data. The NASS CCIs have historically been developed every other year and use a combination of aerial photography, image interpretation, and ground-truthing to establish the best citrus acreage estimates for each county. For years in between discrete CCIs, linear interpolation was used, except in some special circumstances surrounding major freeze years. Often times, the linear interpolation was between discrete acreage data, and occasionally it was from citrus trees counts, derived by density back into citrus acreage.

Special circumstances include the years after the big "impact freezes" of 1957, 1962, 1977, 1981, 1983, 1985, and 1989. Impact freezes are freezes that are "so severe that they annihilate entire groves across the state, killing both mature and young citrus trees, while causing a profound economic impact on the citrus industry and usually prompting growers to replant farther south" (http://www.flcitrusmutual.com/industry-issues/weather/freeze_timeline.aspx). In order to avoid the potential devastation of future freezes on their crop, citrus growers have generally shifted their operations southward following impact freezes. If the data to be interpolated between discrete NASS CCI data was adjacent to an impact freeze year, the NASS CCIs were compared to SJRWMD AWS and other data sources to attempt to determine if missing CCI acreage data would more likely resemble pre- or post-freeze acreages and tree counts. Then, using the more historical (i.e., pre-freeze) data to compute rates of change, the missing data points were interpolated with simple linear interpolation.

NASS CCI tree counts were used often to generate ratios that were used to extrapolate citrus groundwater use or interpolate agricultural groundwater use in the data filling process. The creation of a ratio describing groundwater used per NASS citrus tree reflected a more accurate depiction of the true groundwater usage, since it incorporated the changes in planting densities through time, whereas NASS acreage estimates did not.

ESTIMATING ANNUAL GROUNDWATER USE

CITRUS GROUNDWATER USE ESTIMATION

When determining the best metric for extrapolation, the best, summed or whole county normalized groundwater use estimates for each county from WMD and USGS reports (and occasionally AgCensus reports), were divided by National Agricultural Statistics Service (NASS) Commercial Citrus Inventory (CCI) citrus tree estimates. This approximates groundwater use (in mgd) per citrus tree for each reported or interpolated year. Interpolations used simple, linear algebra whenever possible, and occasionally exponential extrapolation for time periods closest to 1957. Groundwater usage per citrus tree is deemed a better estimator of past or future citrus water use than groundwater usage per citrus acre, because it better accommodates the changes in citrus tree planting density (Figure 2 and 3).

According to the USDA NASS Florida Field Office, citrus tree planting density remained relatively constant from 1966 to 1984, increased sharply from 1984 to 1996, and plateaued from 1996 to present (Figure 2). This likely occurred from advances in technology and the propensity to replant in higher densities following impact freezes in the early 1980s (Figure 3). Note the shift in planting density (Figure 3) following the 1986 low in citrus industry acreage and tree cover in Florida. See Appendix G.

When historical groundwater use data was not explicitly available back to 1957, a method other than linear extrapolation was used to fill missing data points. Extrapolation of groundwater use for earlier years was made by fitting the estimated groundwater use (mgd) data to a curve that described the exponential trend line created from dividing the best water use estimate by the number of NASS CCI estimated citrus trees. The numbers involved are too large for Microsoft Excel to compute, so the data points were approximated onto the curve, to the nearest 0.1 mgd. This method was deemed within the accuracy range of this project.

OTHER AGRICULTURAL CROP GROUNDWATER USE ESTIMATION

Generally speaking, this project uses the terms “ag,” “agricultural,” and “agriculture” to refer to non-citrus agriculture, while “total agriculture” will refer to citrus, non-citrus agriculture, and golf courses combined. In some situations, when it was appropriate, agricultural groundwater use was derived by subtracting citrus groundwater use and golf groundwater use from the total groundwater use. Whenever possible, agricultural groundwater use was computed from discrete data sets in a method similar to citrus. See Appendix F.

Final extrapolation of groundwater use for earlier years was made by assuming that the ratio between citrus groundwater use and overall agricultural groundwater use stayed constant from the year 1985 to 1977 (which coincides with SJRWMD and USGS groundwater use estimates, previous to the big citrus freeze), and all the way back to 1957.

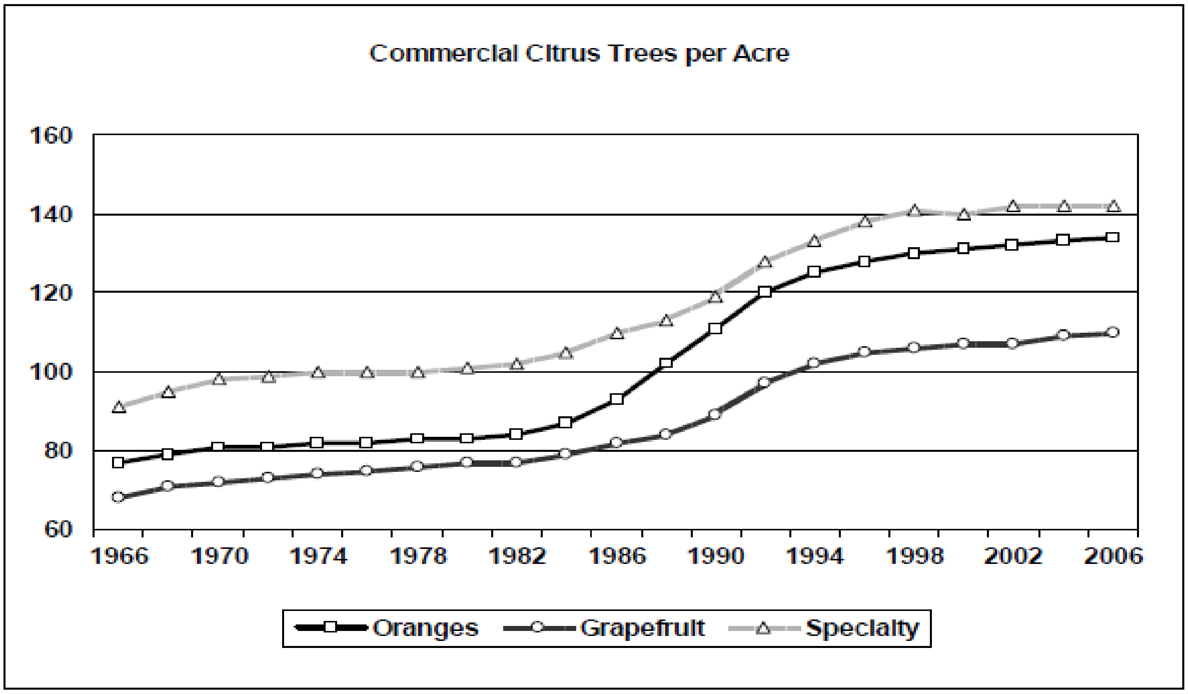

Figure 2. Historical changes in citrus planting densities (source: NASS CCI 2006)

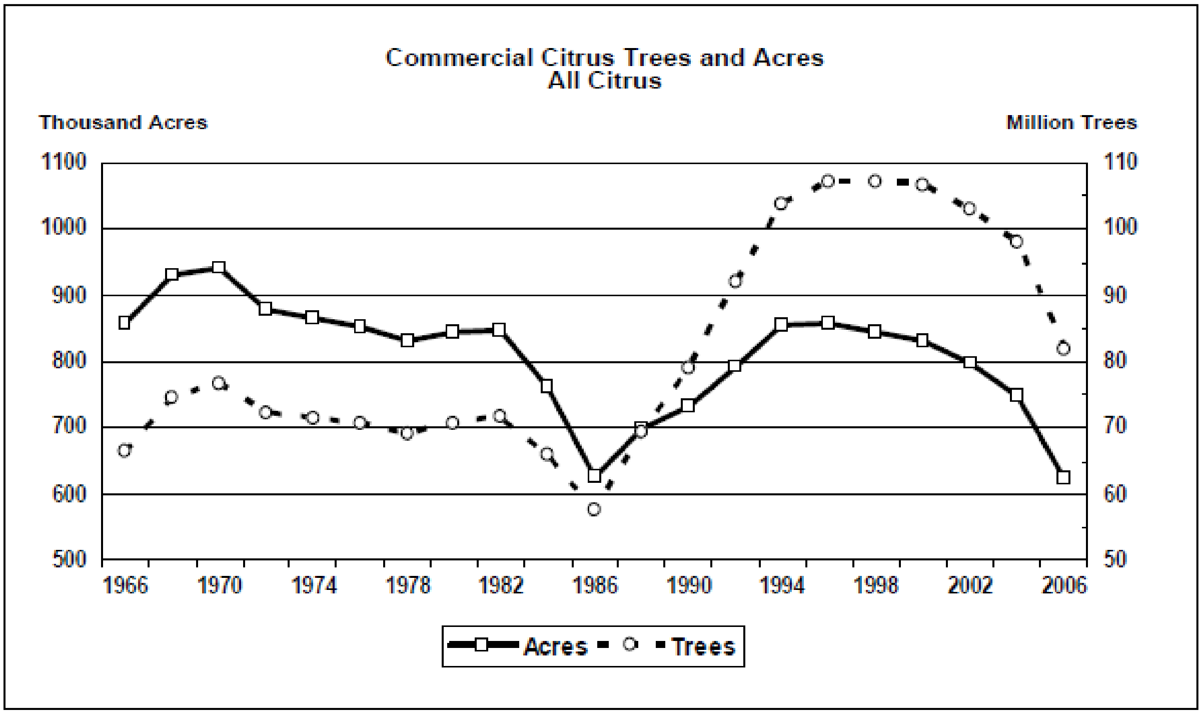

Figure 3. Historical estimates of citrus tree quantity in Florida (source: NASS CCI 2006)

Golf Course Groundwater Use Estimation

Golf water use estimates were developed by using the most recent USGS and WMD data. Often this data does not go back in time further than 1986. Different counties could have their golf groundwater use estimated back to different time periods, from 1977 to 1980, depending on the extrapolation possible using other water use type data. Data filling often relied on ratios of golf groundwater use to total water use, or sometimes, golf water use to either citrus or agricultural water use. See Appendix H.

ESTIMATING MONTHLY GROUNDWATER USE

Monthly distribution of water use was estimated to avoid the simplification that assumes irrigation is distributed equally in all months. As might be expected, given the pattern of climate in central Florida, there was a general increase in irrigation during early spring and a smaller increase in irrigation in early fall.

No explicit attempt was made to accommodate extra irrigation during extenuating circumstances, such as irrigation for freeze protection, chemigation, crop cooling, etc. However, real-world irrigation records were incorporated along with calculated idealized irrigation requirements in the monthly distribution estimation whenever possible. The groundwater use estimates were distributed based on each polygon's proportion of the total acreage within that county for a particular year, multiplied by the monthly proportion of annual irrigation needed, multiplied by the average gallons per day for that year (which was derived from the annual mgd). This provides a resulting water use expressed as average monthly gallons per day for each polygon. These can be summed regionally to provide a general distribution of groundwater use.

In part, the basis for monthly groundwater use distribution was guided by the Florida Supplements to the National Engineering Handbook, part 652, Irrigation Guide, Chapter 4: Water Requirements at *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*, using "normal year" water use requirements for citrus, agriculture, and turf grass (i.e., golf course grass) in the appropriate climate zone. For the purposes of this project, irrigation is also assumed to have been equally distributed among the acreages delineated such that each parcel of land receives an amount of groundwater relative to its proportional amount of the total area of irrigated land for that time period. The final monthly distributions used to allocate groundwater use in this project generally involve conservative estimates of groundwater use. This represents a conservative monthly distribution paradigm that was intentionally incorporated to avoid false positives and extremes in the estimation of groundwater use.

These proportionately monthly distribution values are also entered in the second page of the water use data estimate worksheets (Appendix D), where they are converted into a monthly proportion of groundwater irrigated. The monthly proportion is then multiplied by the annual groundwater use estimate, and by a polygon's proportional area to determine each polygon's estimated monthly groundwater use.

CITRUS MONTHLY GROUNDWATER USE ESTIMATION

Monthly differences in citrus irrigation were determined using the amounts as shown in Table 4, which shows the raw citrus irrigation data that was obtained from different sources. Units are irrelevant, because proportional irrigation regimes are calculated in Table 5. The total average from both climate zones was ultimately used to distribute monthly citrus water use for all counties. This is beneficial because the idealized citrus water use data may tend to underestimate non-evapotranspiration-related water use, such as chemigation, liquid fertilizer application, crop cooling, and freeze protection. Conversely, the year-specific reported data may tend to overestimate those events for the years in which they are extrapolated. Since a year-by-year analysis of these events was beyond the scope of this project, it was determined that an overall average across all climate zones would be a better approximation of real-world conditions than either source group by itself.

Figures 4 and 5 display the data graphically. Although there are extremes in the reported citrus watering regimes for both climate zones (Osceola and Seminole counties), it is apparent that the data trends toward a major spring watering event, with another, smaller fall watering event. These events correspond to the start of the spring growing season, and the fall fruit set. Otherwise, there appears to be a baseline monthly irrigation requirement throughout the year, which is generally near 5%–6% of the annual water use. Notice that irrigation is more evenly distributed annually than the final agricultural annual distribution. A strong spring irrigation signature is noticeable, as well as a smaller fall irrigation event. This is consistent with current, commonly accepted citrus irrigation practices. It was assumed that citrus irrigation requirements and groundwater use are correlated temporally.

Table 4. Raw monthly citrus irrigation requirements

CITRUS GROUNDWATER USE (mgd, or units unknown)															
COUNTY	**CLIMATE ZONE**	**YEAR**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**SUM**
LAKE	3	1995-2002 (avg)	9.615	8.030	7.848	11.508	14.416	8.967	5.212	4.800	4.326	6.313	7.013	7.427	95.48
ORANGE	3	1995-2002 (avg)	2.624	3.149	3.578	5.099	5.948	4.900	3.040	2.736	2.531	3.753	3.421	2.849	43.63
OSCEOLA	4	2002	9.7	2.283	19.854	30.153	16.49	0	0	0	3.791	23.552	9.78	0	115.60
POLK	4	2000	3.1	6.02	5.09	6.21	6.57	4.14	2.91	2.83	2.73	3.38	3.39	3.71	50.08
POLK	4	1995-2002 (avg)	4.289	5.828	6.103	7.274	7.678	4.175	2.469	2.423	2.497	3.405	3.143	3.473	52.76
POLK	4	2001	10.33	5.56	5.49	10.33	11.85	6.54	1.39	0.81	2.8	5.38	3.99	4.97	69.44
Seminole	3	2002	0.412	1.733	4.311	6.168	7.887	0.000	1.348	0.000	3.409	5.647	2.295	0.000	33.21
all	3	idealized	0.80	0.06	0.76	1.95	2.14	1.26	1.33	1.02	0.97	1.73	0.91	0.85	13.78
all	4	idealized	1.15	0.40	1.07	2.33	2.19	1.24	1.33	1.01	0.91	1.76	1.19	1.25	15.83
Source: Best Management Farms program (Citrus_BMF1995-2002.xls), Ag_Model_Report2002.xls, PolkCounty2001-01.xls, ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf, and USGS_FILES_FROM_BRUCE_FLORENCE.															

Table 5. Proportional monthly citrus irrigation requirements

Proportional citrus groundwater use														
COUNTY	**CLIMATE ZONE**	**YEAR**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
all, idealized	3	Average	0.058	0.004	0.055	0.142	0.155	0.091	0.097	0.074	0.070	0.126	0.066	0.062
all, idealized	4	Average	0.073	0.025	0.068	0.147	0.138	0.078	0.084	0.064	0.057	0.111	0.075	0.079
LAKE	3	Average	0.101	0.084	0.082	0.121	0.151	0.094	0.055	0.050	0.045	0.066	0.073	0.078
ORANGE	3	Average	0.060	0.072	0.082	0.117	0.136	0.112	0.070	0.063	0.058	0.086	0.078	0.065
OSCEOLA	4	Average	0.084	0.020	0.172	0.261	0.143	0.000	0.000	0.000	0.033	0.204	0.085	0.000
POLK	4	Average	0.081	0.110	0.116	0.138	0.146	0.079	0.047	0.046	0.047	0.065	0.060	0.066
SEMINOLE	3	Average	0.012	0.052	0.130	0.186	0.237	0.000	0.041	0.000	0.103	0.170	0.069	0.000
ALL	3	Average	0.058	0.053	0.087	0.141	0.170	0.074	0.065	0.047	0.069	0.112	0.072	0.051
ALL	4	Average	0.079	0.052	0.118	0.182	0.142	0.052	0.044	0.037	0.046	0.126	0.073	0.048
ALL	Both	Average	0.069	0.053	0.103	0.162	0.156	0.063	0.054	0.042	0.057	0.119	0.072	0.050
Source: Best Management Farms program (Citrus_BMF1995-2002.xls), Ag_Model_Report2002.xls, PolkCounty2001-01.xls, ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf, and USGS_FILES_FROM_BRUCE_FLORENCE.														

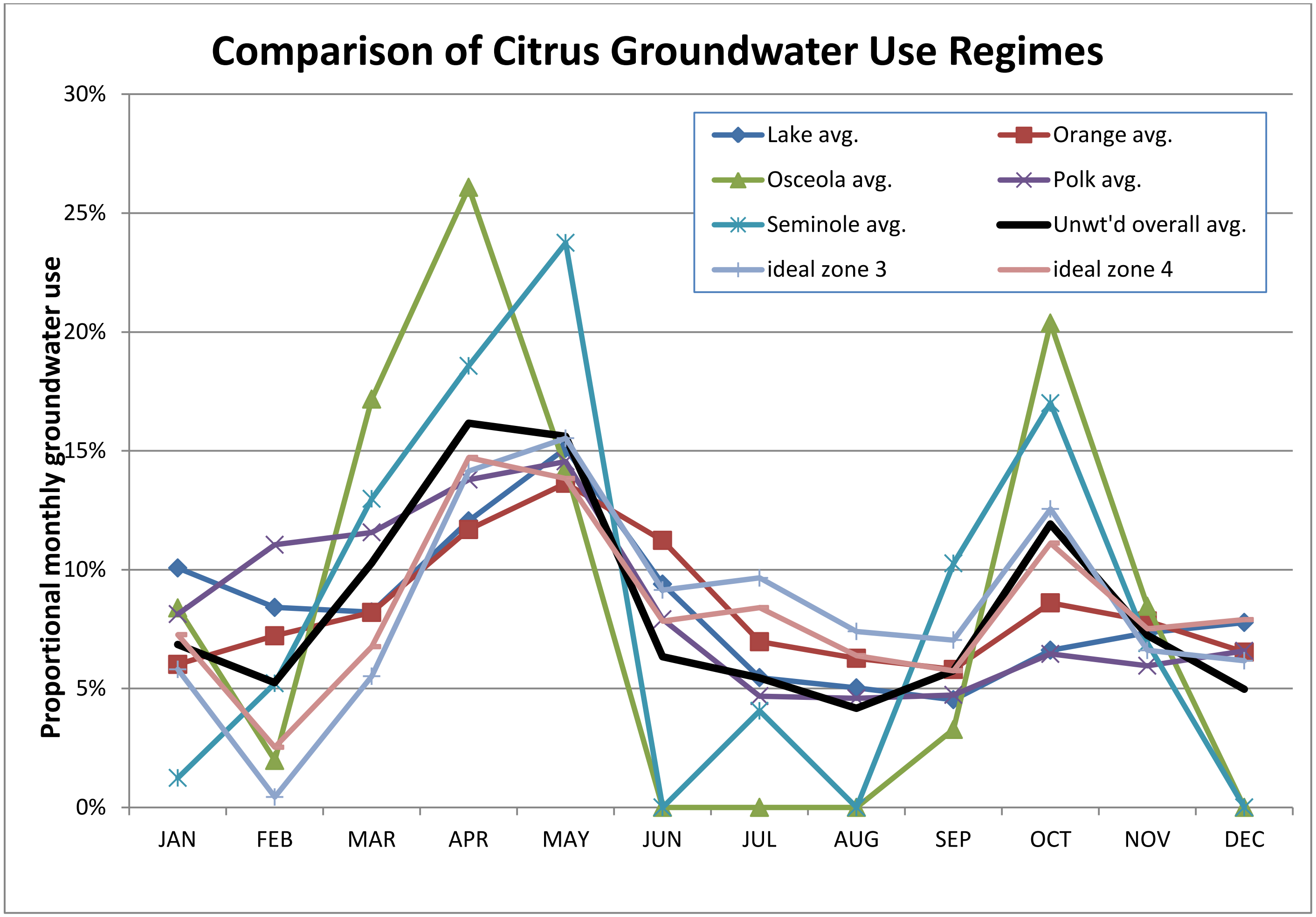

Figure 4. Comparison of average monthly citrus irrigation regimes by county

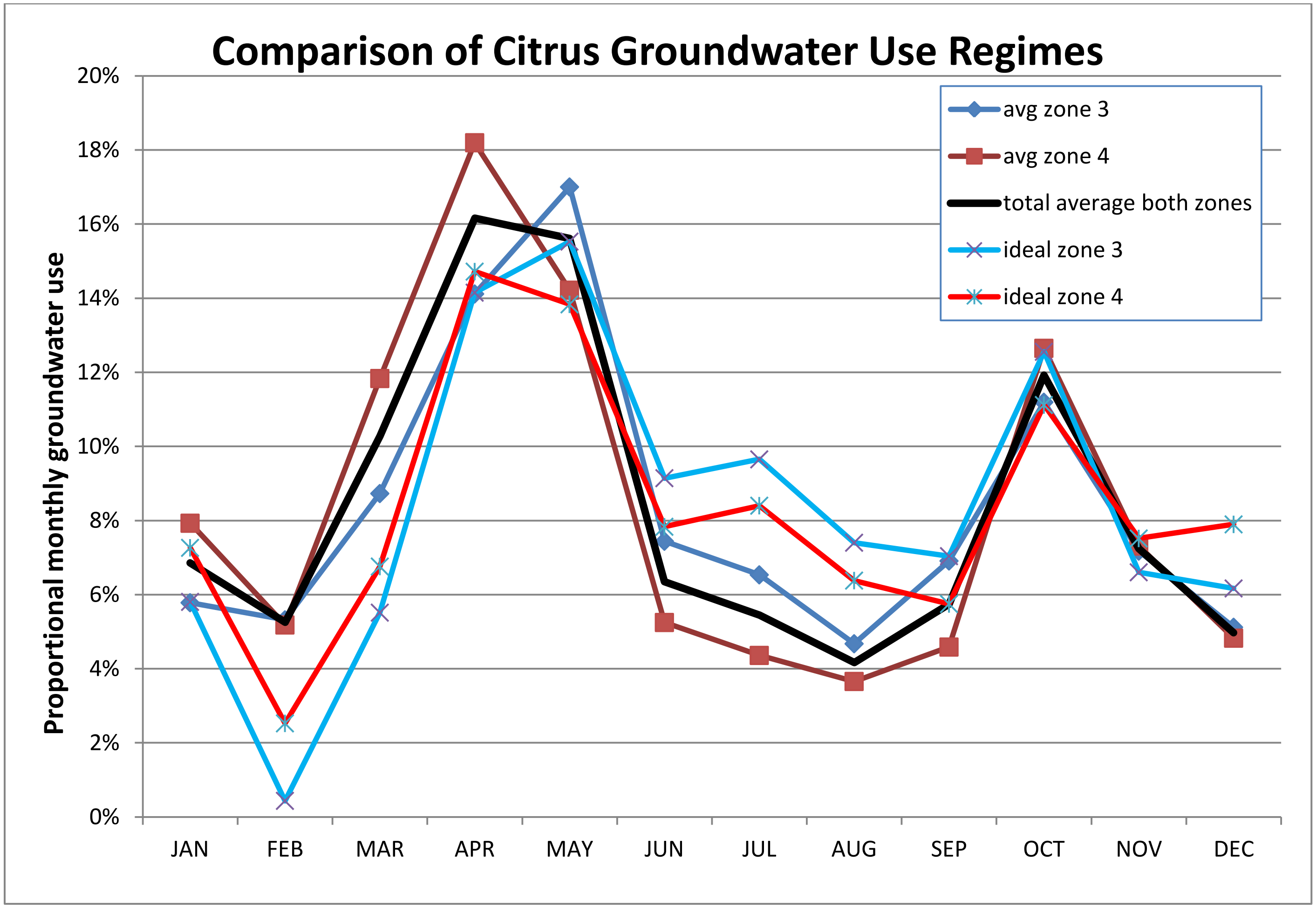

Figure 5. Comparison of average monthly citrus irrigation regimes, averaged by climate zone

OTHER AGRICULTURAL CROP GROUNDWATER USE ESTIMATION

Monthly irrigation requirements for other agricultural crops were determined in a fashion similar to citrus. However, since non-citrus agriculture encompasses many different crops with different watering regimes, it was necessary to determine major regional crops, and average their water use accordingly. Crops that regularly occupied vast acreages were considered to be major crops.

The counties in the CFCA span USDA climate zones 3 and 4 (*ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*); Lake, Orange, and Seminole counties are in Zone 3; and Osceola and Polk counties are in Zone 4. In part, selection of crops was based on SJRWMD's 1991 Annual Water Use Survey, focusing on crops that significantly contributed to CFCA water use (Table 6). Using primarily only major crop types for the area proved to be a useful technique, because it tended to focus the project. However, no attempt was made to determine the proportional contribution of any crop type. Therefore, an unweighted average distribution of the annual water use estimate was used. The crop list represents the best available data from historical records regarding not only the predominant crops present in the CFCA, but also their traditional and/or idealized irrigation regimes (*ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/ nehfl652ch_4.pdf*). The list of crops in these tables is not a comprehensive list of the crops grown in the area. An unweighted average of monthly crop water use distribution was used in the interest of project scope, and the difficulty of estimating proportional crop contribution temporally for this historical data set. It was determined unfeasible to determine the relative proportion of each crop in each county for the time period encompassed in this project.

Monthly distribution is estimated in AgWaterUse_AnnualDistr.xlsx and represents a modified unweighted average of monthly irrigation values for the most common vegetables and other plants present in the counties (Table 7, 8, and 9). These monthly water use distribution estimates represent a better alternative than simply dividing the annual water use estimates by 12 months. The important trend revealed is that most irrigation occurs in spring with another, smaller irrigation period in late fall (Figure 6, 7, and 8). Again, it was assumed that a correlation between irrigation and groundwater use was present.

Table 6. Major crops in the CFCA

ZONE	MAJOR CROP?	CROP
3	Y	CORN GRAIN
3	Y	CORN FIELD
3	Y	CORN SWEET
3	?	ORNAMENTALS CONTAINER
3	Y	MISC. VEGETABLES
3	Y	CARROTS
3	Y	MELON/CANTALOUPE
3	N	SOYBEAN
4	Y	CORN GRAIN
4	Y	CORN SWEET
4	?	ORNAMENTALS FIELD
4	?	ORNAMENTALS CONTAINER
4	?	MISC. VEGETABLES
4	Y	CARROTS
4	Y	MELON/CANTALOUPE
Note: In part, selection of crops was based on SJRWMD's 1991 Annual Water Use Survey, focusing on crops that significantly contributed to CFCA water use.		
Note: Soybean is a minor crop, but it was included to reduce bias toward only early year crops.		
Data sources: Ag_Model_Report2002.xls, and *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*		

Table 7. Climate zone 3 crops and reported monthly water use

Zone 3			Monthly water use (raw data, units irrelevant)												
County	Year	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
ALL	ideal	CORN GRAIN		0	1.430	3.500	2.770								7.70
LAKE	2002	CORN FIELD			0.503	0.997	0.939	0.001	0						2.44
ALL	ideal	CORN SWEET			0.370	3.420	3.630								7.42
ORANGE	2002	CORN SWEET		0	0.141	0.101	0.206	0	0						0.45
LAKE	2002	CORN SWEET		0	0.088	0.064	0.171	0	0.015						0.34
LAKE	2002	ORNAMENTALS CONTAINER	2.369	3.651	6.613	7.813	9.551	0	3.525	0	2.330	3.752	4.171	0	43.78
ORANGE	2002	ORNAMENTALS CONTAINER	0.547	0.464	1.242	1.369	1.492	0.104	0.458	0.276	0.786	0.523	0.614	0	7.88
ORANGE	2002	MISC. VEGETABLES			0.089	0.188	0.190	0							0.47
LAKE	2002	MISC. VEGETABLES			0.218	0.568	0.653	0							1.44
ALL	ideal	CARROTS									0.060	2.230	1.07	0.500	3.86
ORANGE	2002	CARROTS	0.012	0.005	0.021	0.020	0.003					0	0.012	0	0.07
LAKE	2002	MELON/CANTALOUPE			0.020	0.605	0.317	0							0.94
ALL	ideal	MELON/CANTALOUPE		0	0.680	2.910	1.240								4.83
ALL	ideal	SOYBEAN						0.690	1.100	2.350	2.070	0.770			6.98

Note: In part, selection of crops was based on SJRWMD’s 1991 Annual Water Use Survey, focusing on crops that significantly contributed to CFCA water use.

Note: Soybean is a minor crop, but it was included to reduce bias toward only early year crops.

Data sources: Ag_Model_Report2002.xls, and *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*

Table 8. Climate zone 4 crops and reported monthly water use

Zone 4			Monthly water use (raw)												
County	Year	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
ALL	ideal	CORN GRAIN		0.170	1.780	3.960	2.810								8.72
ALL	ideal	CORN SWEET			0.670	3.880	3.690								8.24
SEMINOLE	2002	ORNAMENTALS FIELD	0.000	0.286	1.012	1.594	2.052	0.000	0.373	0.000	0.850	1.226	0.384	0.000	7.78
SEMINOLE	2002	ORNAMENTALS CONTAINER	0.350	0.664	1.189	1.580	1.889	0.000	0.828	0.081	1.009	1.239	0.668	0.000	9.50
POLK	2002	ORNAMENTALS CONTAINER	0.122	0.100	0.238	0.327	0.252	0.000	0.122	0.086	0.128	0.236	0.135	0.000	1.75
SEMINOLE	2002	MISC. VEGETABLES			0.039	0.116	0.132	0.000							0.29
ALL	ideal	CARROTS									0.030	2.280	1.370	0.500	4.18
ALL	ideal	MELON/CANTALOUPE	0.820	0.480	1.880	3.170	2.030								8.38
Note: In part, selection of crops was based on SJRWMD's 1991 Annual Water Use Survey, focusing on crops that significantly contributed to CFCA water use.															
Data sources: Ag_Model_Report2002.xls, and *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*															

Table 9. Averaged monthly water use for crops in all climate zones in the CFCA

Zone 3 and 4 combined		Averaged proportional monthly water use											
Zone	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3	CORN FIELD/GRAIN	0	0	0.196	0.432	0.372	0	0	0	0	0	0	0
3	CORN SWEET	0	0	0.208	0.292	0.485	0	0.015	0	0	0	0	0
3	ORNAMENTALS CONTAINER	0.062	0.071	0.154	0.176	0.204	0.007	0.069	0.018	0.077	0.076	0.087	0
3	CARROTS	0.082	0.034	0.144	0.137	0.021	0	0	0	0.008	0.289	0.221	0.065
3	MELON/CANTAL OUPE	0	0	0.081	0.622	0.297	0	0	0	0	0	0	0
3	MISC. VEGETABLES	0	0	0.081	0.622	0.297	0	0	0	0	0	0	0
3	SOYBEAN	0	0	0	0	0	0.099	0.158	0.337	0.297	0.110	0	0
4	CORN GRAIN	0	0.019	0.204	0.454	0.322	0	0	0	0	0	0	0
4	CORN SWEET	0	0	0.081	0.471	0.448	0	0	0	0	0	0	0
4	ORNAMENTALS CONTAINER	0.053	0.064	0.131	0.177	0.172	0	0.079	0.029	0.090	0.133	0.074	0
4	MISC. VEGETABLES	0	0	0.136	0.404	0.460	0	0	0	0	0	0	0
4	CARROTS	0	0	0	0	0	0	0	0	0.007	0.545	0.328	0.120
4	MELON/CANTAL OUPE	0.098	0.057	0.224	0.378	0.242	0	0	0	0	0	0	0
3	MAJOR CROPS UNWEIGHTED	0.016	0.007	0.142	0.421	0.294	.00004	0.003	0	0.002	0.058	0.044	0.013
3	ALL CROPS UNWEIGHTED	0.021	0.015	0.123	0.326	0.239	0.015	0.035	0.051	0.054	0.068	0.044	0.009
4	MAJOR CROPS UNWEIGHTED	0.030	0.028	0.128	0.296	0.237	0	0.016	0.006	0.019	0.136	0.080	0.024
4	ALL CROPS UNWEIGHTED	0.025	0.023	0.129	0.314	0.274	0	0.013	0.005	0.016	0.113	0.067	0.020
Both	MAJOR CROPS UNWEIGHTED	0.023	0.017	0.135	0.359	0.265	.00002	0.009	0.003	0.010	0.097	0.062	0.018
Both	ALL CROPS UNWEIGHTED	0.023	0.019	0.126	0.320	0.257	0.008	0.024	0.028	0.035	0.090	0.055	0.015

Note: Continued next page.
In part, selection of crops was based on SJRWMD's 1991 Annual Water Use Survey, focusing on crops that significantly contributed to

CFCA water use.
Note: Soybean is a minor crop, but it was included to reduce bias toward only early year crops, and a value greater than zero was required for all months.
Data sources: Ag_Model_Report2002.xls, and *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*

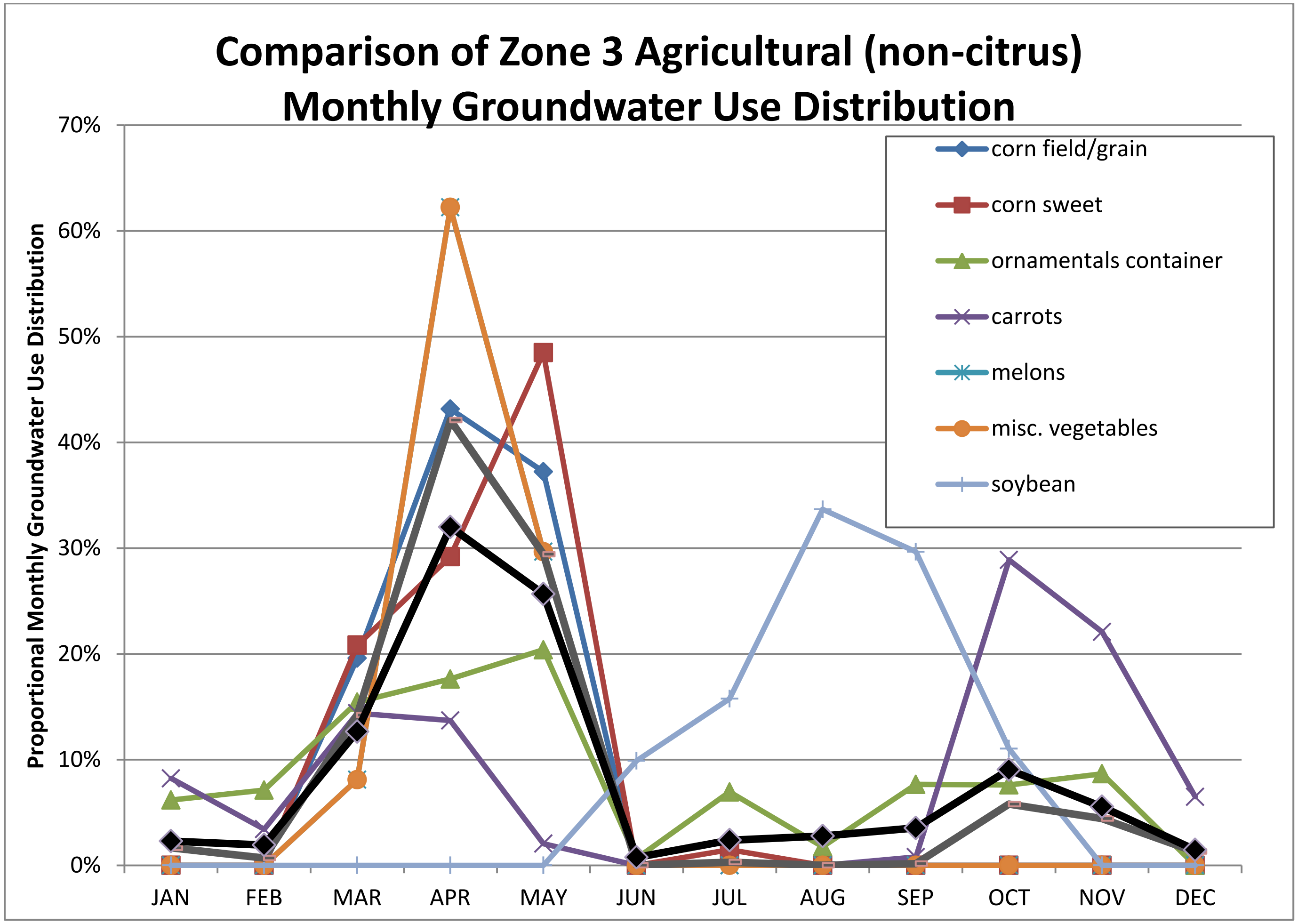

Figure 6. Climate zone 3 agricultural monthly groundwater use distribution comparison

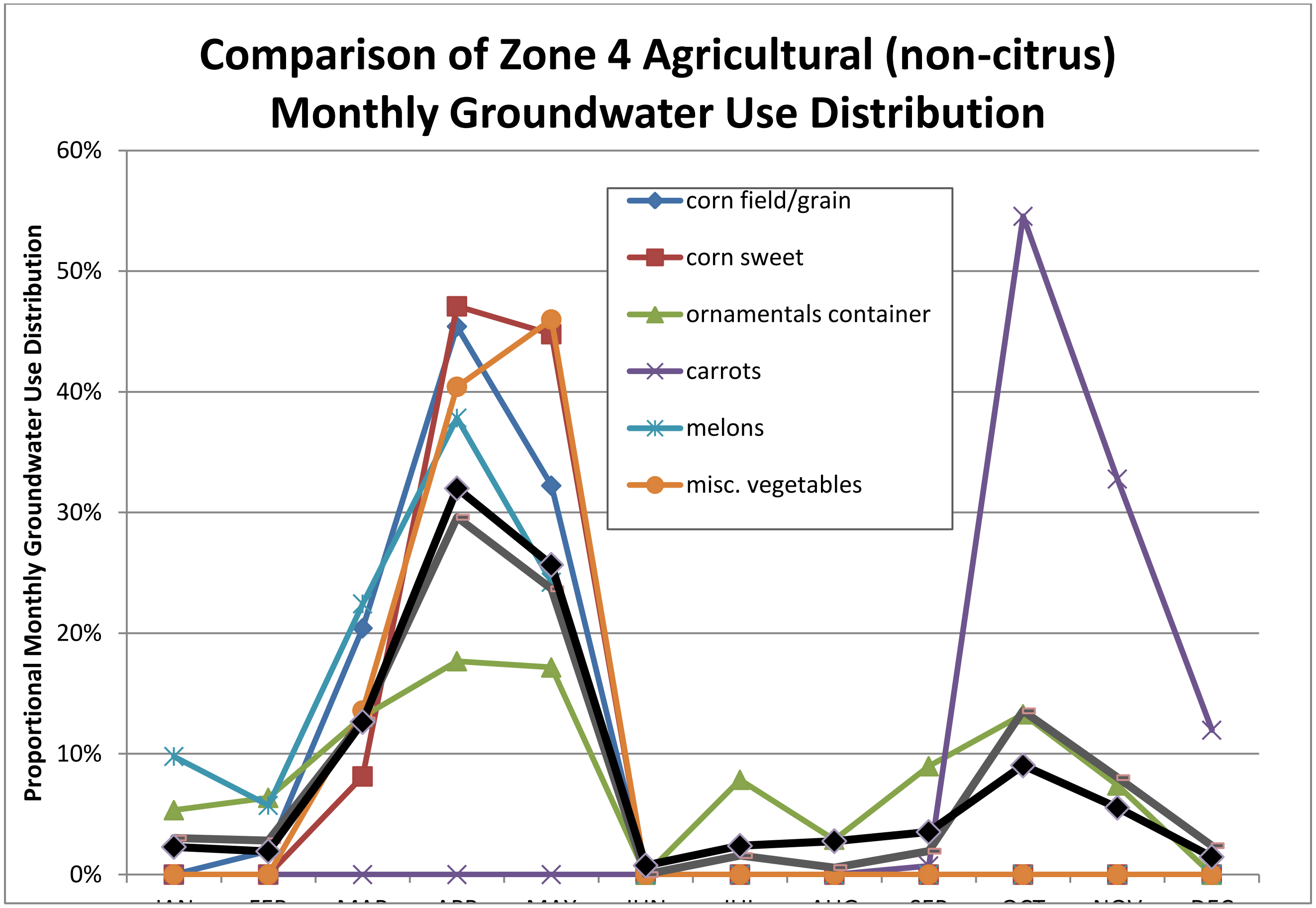

Figure 7. Climate zone 4 agricultural monthly groundwater use distribution comparison

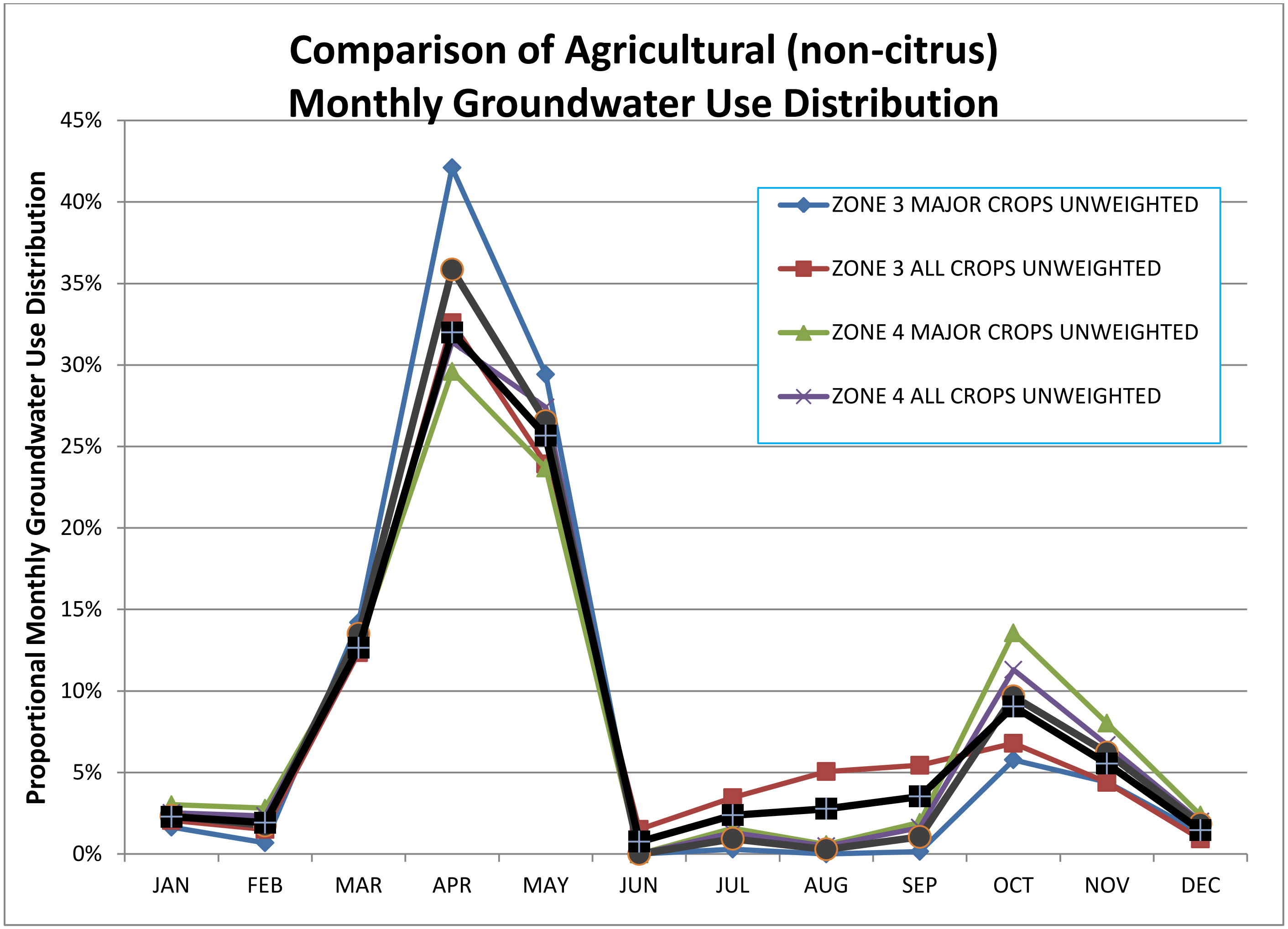

Figure 8. Average agricultural monthly groundwater use distribution comparison for all counties

GOLF COURSE GROUNDWATER USE ESTIMATION

Groundwater use was estimated for each golf course in the exact same proportional distribution method as was used for citrus and other agricultural crops. This method assumes even irrigation distribution, based on proportional acreage, and uses turf grass irrigation requirements from WMD estimates (Table 10). Data was unobtainable for Osceola County. The Polk County 2001 data seems to be contrary to the trends in the other counties. Without data from another climate zone 4 county (Osceola) to corroborate that trend, it was determined to be a more conservative approach to use the average of all climate zones, to prevent possible distortion. The final data was averaged together by county and used as a general estimate of monthly irrigation requirements for golf courses (Table 11). This data shows that most turf watering occurs in the spring and that overall watering for any month rarely falls below 6% of the annual amount (Figure 9).

Golf courses are assumed to have been irrigated fully since their establishment/creation, at the monthly rates estimated in GolfWaterUse_AnnualDistr.xlsx. These estimates do not include irregular, unaccounted-for water uses, such as plant establishment, turf cooling, chemigation, or fertilizer application. The unweighted, overall average of golf course watering regimes was used for all counties due to the long time span covered by this project. This overall average is assumed to be more accurate than simply dividing annual water use by 12 months.

Table 10. Raw monthly golf course irrigation requirements by county

GOLF GROUNDWATER USE (mgd, or units unknown)															
COUNTY	**CLIMATE ZONE**	**YEAR**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**SUM**
LAKE	3	2002	1.969	3.520	5.950	6.233	7.119	5.321	4.647	3.559	4.367	5.447	3.403	2.995	54.53
LAKE	3	2001	3.898	3.920	3.926	5.524	6.102	5.672	4.434	5.363	4.064	7.141	6.342	5.311	61.70
LAKE	3	2000	1.969	3.520	5.950	6.233	7.119	5.321	4.647	3.559	4.367	5.447	3.403	2.995	54.53
ORANGE	3	2001	0.627	1.394	1.152	2.081	2.171	1.783	1.885	1.884	1.655	1.983	1.536	2.071	20.22
ORANGE	3	2002	4.651	7.244	9.651	9.162	11.968	8.334	9.773	8.571	4.986	8.013	6.516	4.338	93.21
OSCEOLA	4	DATA NOT AVAILABLE													
POLK	4	2001	0.046	0.051	0.046	0.048	0.046	0.048	0.033	0.038	0.027	0.007	0.029	0.03	0.45
SEMINOLE	3	2001	0.083	0.990	0.740	1.251	1.085	0.686	0.938	0.135	0.684	1.090	1.396	1.424	10.50
SEMINOLE	3	2002	4.170	5.938	8.386	8.697	11.399	9.294	5.053	7.351	3.743	7.001	5.551	4.307	80.89
Source: USGS_FILES_FROM_BRUCE_FLORENCE, 2001_GOLF_COURSES_FINAL.xls															

Table 11. Proportional average monthly golf course irrigation requirements

Proportional citrus groundwater use														
COUNTY	**CLIMATE ZONE**	**YEAR**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
LAKE	3	AVERAGE	0.050	0.064	0.086	0.102	0.115	0.095	0.079	0.076	0.073	0.108	0.083	0.071
ORANGE	3	AVERAGE	0.040	0.073	0.080	0.101	0.118	0.089	0.099	0.093	0.068	0.092	0.073	0.074
OSCEOLA	4	AVERAGE	DATA NOT AVAILABLE											
POLK	4	AVERAGE	0.102	0.114	0.102	0.107	0.102	0.107	0.073	0.085	0.060	0.016	0.065	0.067
SEMINOLE	3	AVERAGE	0.030	0.084	0.087	0.113	0.122	0.090	0.076	0.052	0.056	0.095	0.101	0.094
ALL	3	AVERAGE	0.040	0.074	0.085	0.105	0.118	0.091	0.084	0.074	0.065	0.098	0.085	0.080
ALL	4	AVERAGE	0.102	0.114	0.102	0.107	0.102	0.107	0.073	0.085	0.060	0.016	0.065	0.067
ALL	Both	AVERAGE	0.056	0.084	0.089	0.106	0.114	0.095	0.082	0.076	0.064	0.078	0.080	0.077
Source: USGS_FILES_FROM_BRUCE_FLORENCE, 2001_GOLF_COURSES_FINAL.xls														

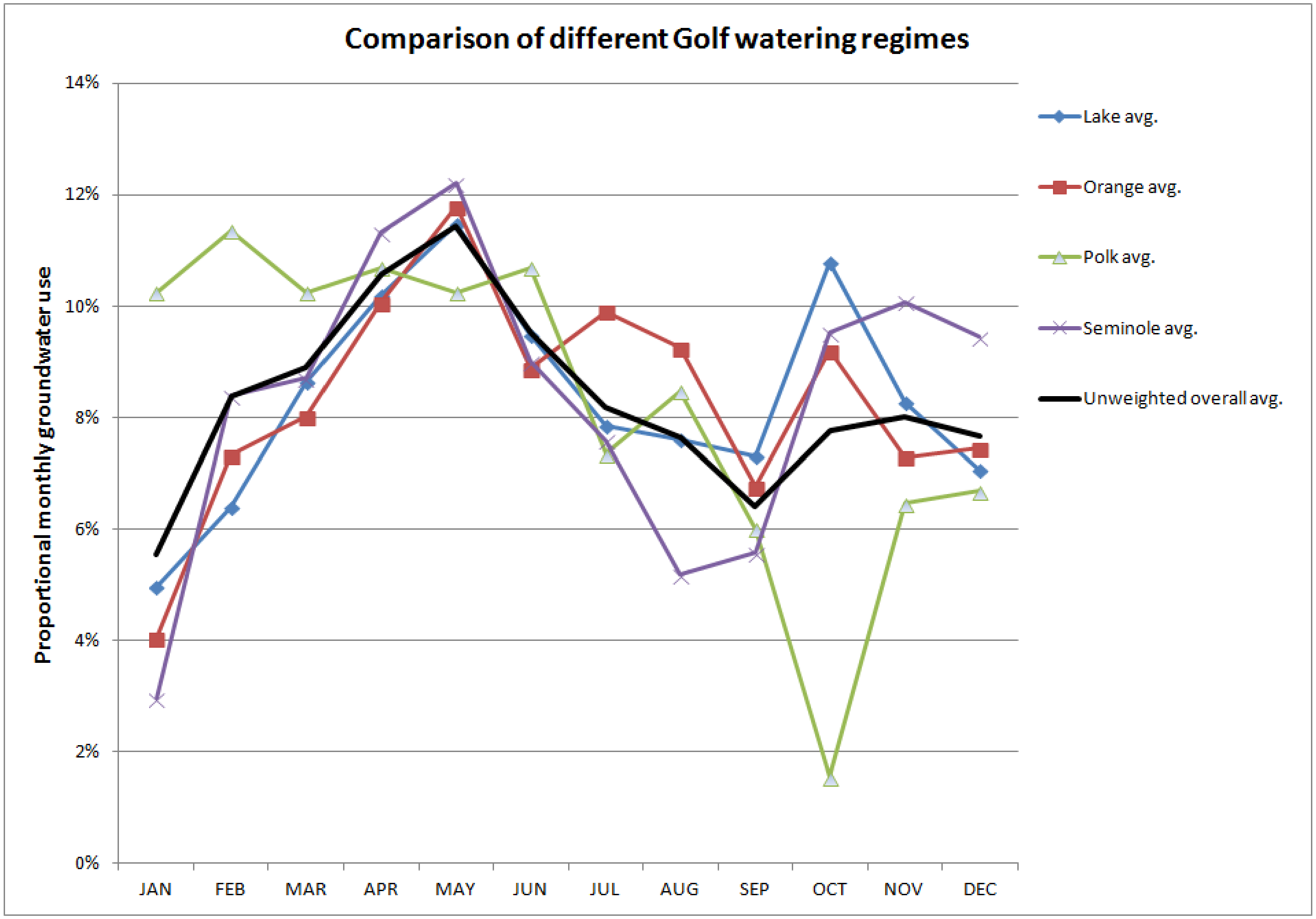

Figure 9. Comparison of average monthly golf course irrigation regimes by county

MONTHLY DISTRIBUTION ESTIMATION

For citrus, although Osceola and Seminole proportional monthly distribution data had an extremely variable range (Figures 4 and 5), the unweighted average used in this project to distribute groundwater use was more moderated. It appears that when compared to the reported data from years in the early 2000s, the idealized proportional irrigation distribution proposed by the Florida National Engineering Handbook (FL NEH) had lower February application rates, and higher summer application rates. This is likely because the NEH figures do not include irrigation for freeze protection. Thus, the unweighted average that combines idealized groundwater use regimes with averages of reported data for dominant crops, probably better approximates the general trends in groundwater use seen across the CFCA for the long time period encompassed by this project.

The unweighted average monthly distribution estimation technique created a reasonably intuitive proportional distribution curve for all water use types. This curve was more reflective of reality than an equally distributed scenario. The unweighted average method created a mildly conservative monthly distribution of water use. The agricultural unweighted average curve tended to moderate strong peaks in spring and fall irrigation (Figure 8). Although the actual distribution of crops and irrigation schemes may indeed have these strong seasonal irrigation signatures, it benefits this project not to overestimate any particular season's groundwater use. Moderation of the range of the monthly distribution data was beneficial.

For golf courses, there were fewer reported data sources to derive monthly distributions. Hence, a more moderated curve, tending more toward the equal distribution of groundwater in all months is illustrated (Figure 9). The proportional monthly distribution of groundwater still tended toward more use in spring, but it was definitely more evenly distributed. Data collected for Polk County had a distinctive curve that was not similar to other counties. However, without other years or other climate zone 4 counties (i.e., Osceola) to back up that trend, it was decided that an unweighted average better approximated the general monthly groundwater use of the CFCA.

RESULTS

SPATIAL TRENDS IN AGRICULTURAL ACREAGE ESTIMATES

The following maps, although containing a large uncertainty in terms of acreages, still show a relative change in the spatial distribution of certain water use types through time. Remember that the project assumption for agriculture (Figure 10) and citrus (Figure 11) is that areas present in 2010 have always been present and that other agricultural areas, which may be been cultivated in the past, have been lost to development, a cessation in cultivation, or for other reasons. This assumption was made due to logistical impossibilities associated with determining how acreages might have been lost or gained through time using the LULC GIS data that was available. Golf (Figure 12) is different; older courses were presumed to have been created in the year they were delineated from the GIS data, and are assumed to still be in operation in present-day.

Figure 11 clearly exhibits a trend of southerly movement in citrus acreages through time. There are several possible causes for this observation. The first is the loss of citrus land to development and the other being the loss of citrus resulting from severe freeze events. An example scenario such as, growers in Lake Co. did not replant while at the same time Polk County growers also suffered losses but replanted in areas further south. Even so, this trend is collaborated by reports of citrus growers moving further south following some of the devastating freezes of the late 1970s and early 1980s (NASS, and *http://www.flcitrusmutual.com/industry-issues/weather/freeze_timeline.aspx*). This trend is also mimicked in the estimated groundwater use computed during this project (Table 12, Figure 11). Ag also mimics this trend, albeit not as strongly (Figure 10). Ag can be seen to have been displaced in the central part of the CFCA, possibly by urban development.

The trend in the development of golf courses is centered on the Orlando area, in south central Orange County (Figure 12). That is where the first occurrences of golf courses appear in the GIS data. It would seem that initially golf courses were developed in this area as Orlando grew as a recreational hub, but in years closer to present, there was increased golf course development in areas further south, such as central Polk County, which currently has a higher population of retirees and seniors than the state average (US Census 2010). Overall, increased urban development in the area through time has likely added to the acreage of golf course areas.

TOTAL AGRICULTURE GROUNDWATER USE ESTIMATES

Table 12 displays the groundwater use estimates by county and water use type. These are the annual groundwater use estimates that were used to derive the monthly estimates on (based on the monthly distribution estimates) the spatial acreage delineated in this project. Table 13 displays the compiled total agricultural (ag, citrus, and golf) groundwater use estimated for the entire time period. Polk and Lake counties are estimated to have used the most groundwater use throughout the time frame of this project, relative to the other counties.

For comparative purposes, previous historical estimates of citrus and total agricultural groundwater use have been reported in U.S. Geological Survey (USGS) or Florida Geological Survey reports. Stewart (1966) reported groundwater use for citrus irrigation in Polk County in 1959 at approximately 23.56 mgd, which compares favorably with the estimate of 22.74 mgd reported in Table 13. Litchler et.al. (1968) reported an estimated 5.5 mgd of groundwater use for agriculture in Orange County A majority of that groundwater was used, in part, for the estimated 63,000 acres of citrus. This estimate compares favorably with water use estimate in Table 13 for Orange County citrus of 5.64 mgd. Marrella (1995) estimates 14.08 mgd for agricultural groundwater use for Lake County in 1965. This is significantly lower than the estimate of 74.13 mgd shown in Table 13 for Lake County. This could be the result of the inability to separate groundwater from surface water sources for agricultural irrigation in the county. However, estimates for Lake County from the USGS (*http://fl.water.usgs.gov/WaterUse/hwu_h-m.htm*) become more consistent with the values shown in Table 13 by the mid-1970s, which may bring in question the earlier estimates. Although only a sample, these comparisons reinforce the utility of this GIS based model. A source of data for additional comparisons is available at *http://fl.water.usgs.gov/WaterUse/hwu_FL.htm*.

Figure 13 shows the estimated groundwater use for all water use types combined by decade: citrus, non-citrus agriculture, and golf courses. Overall, groundwater use peaked in the 1980’s, although trends differ between counties. Trends of peaking total agricultural (ag, citrus, and golf) groundwater use are present in Orange and Lake counties in the 1970s and 1980s. After the 1980s, there appears to be a shift toward agricultural groundwater use in Polk and to a lesser degree Osceola), as citrus developed southward during the last 30 years (also see Appendix I).

Figure 14 illustrates the relative proportional distribution of total agricultural water use by county in 10-year increments within the CFCA. These charts illustrate large total agricultural groundwater use in Lake, Orange, and Seminole counties in the earlier years (1950–1980s) and shows an increase in groundwater use Polk and Osceola counties in the 1990s and 2000s.

Figure 15 shows the estimated groundwater use for all counties by water use type. Compared to agriculture and golf, notice that citrus is the historically dominant driver in groundwater use for all counties except Orange, and possibly Seminole, where agriculture is historically dominant. In the northern half of the CFCA, Lake, Orange and Seminole counties have trended toward less agricultural and citrus groundwater withdrawals, while the southern counties (primarily Polk) have experienced increased groundwater use, primarily as a result of citrus growers migrating southward following the impact freezes of the early 1980s.

Figure 16 illustrates that over the past three decades, citrus production has primarily driven the groundwater use of Lake, Osceola, and Polk counties. In Orange and Seminole counties, agriculture, other than citrus, is the primary consumer of groundwater.

Figure 17 displays combined total agricultural (ag, citrus, and golf) groundwater use for each county over the entire time span of this project. Polk and Lake counties have used the most aggregate estimated groundwater since 1957. They are vast counties with a tradition of citrus cultivation.

Figure 18 shows decadal trends in estimated groundwater use for total agriculture (ag, citrus, and golf) for the CFCA. Groundwater use peaked in the 1970s and 1980s, at the height of citrus cultivation, but has tapered off in the past two decades.

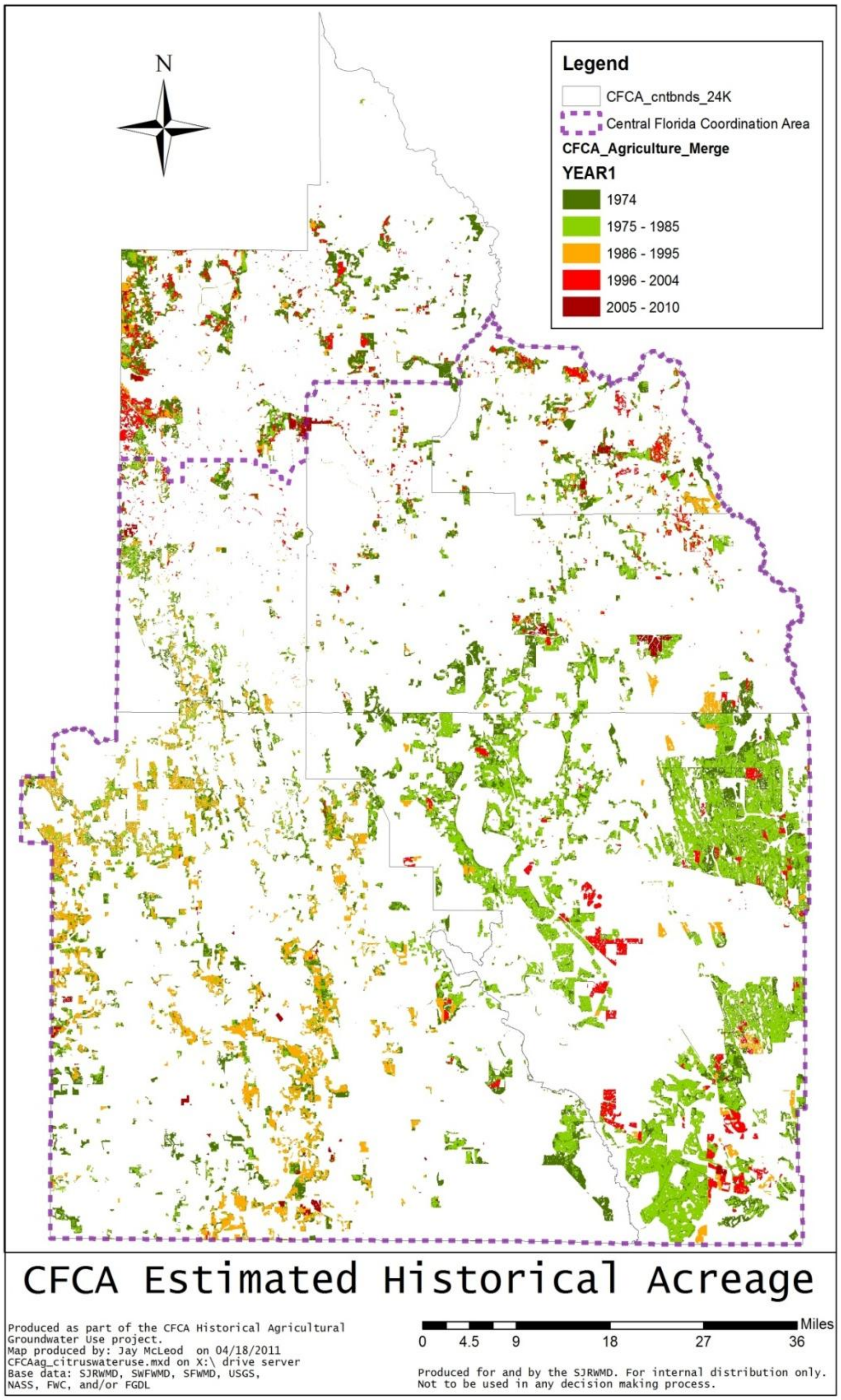

Figure 10. Estimated relative distribution of historical non-citrus agricultural acreages

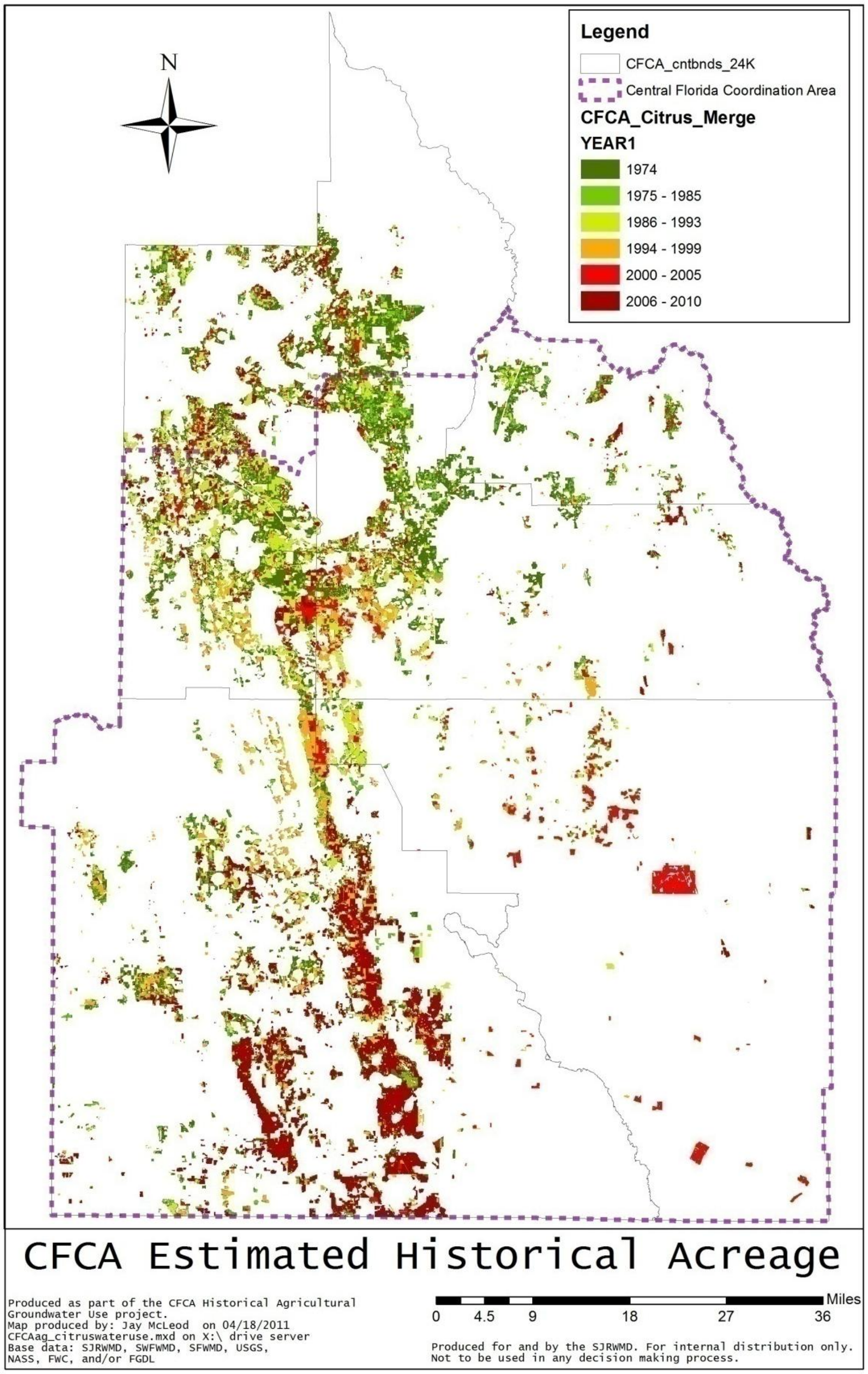

Figure 11. Estimated relative distribution of historical citrus acreages

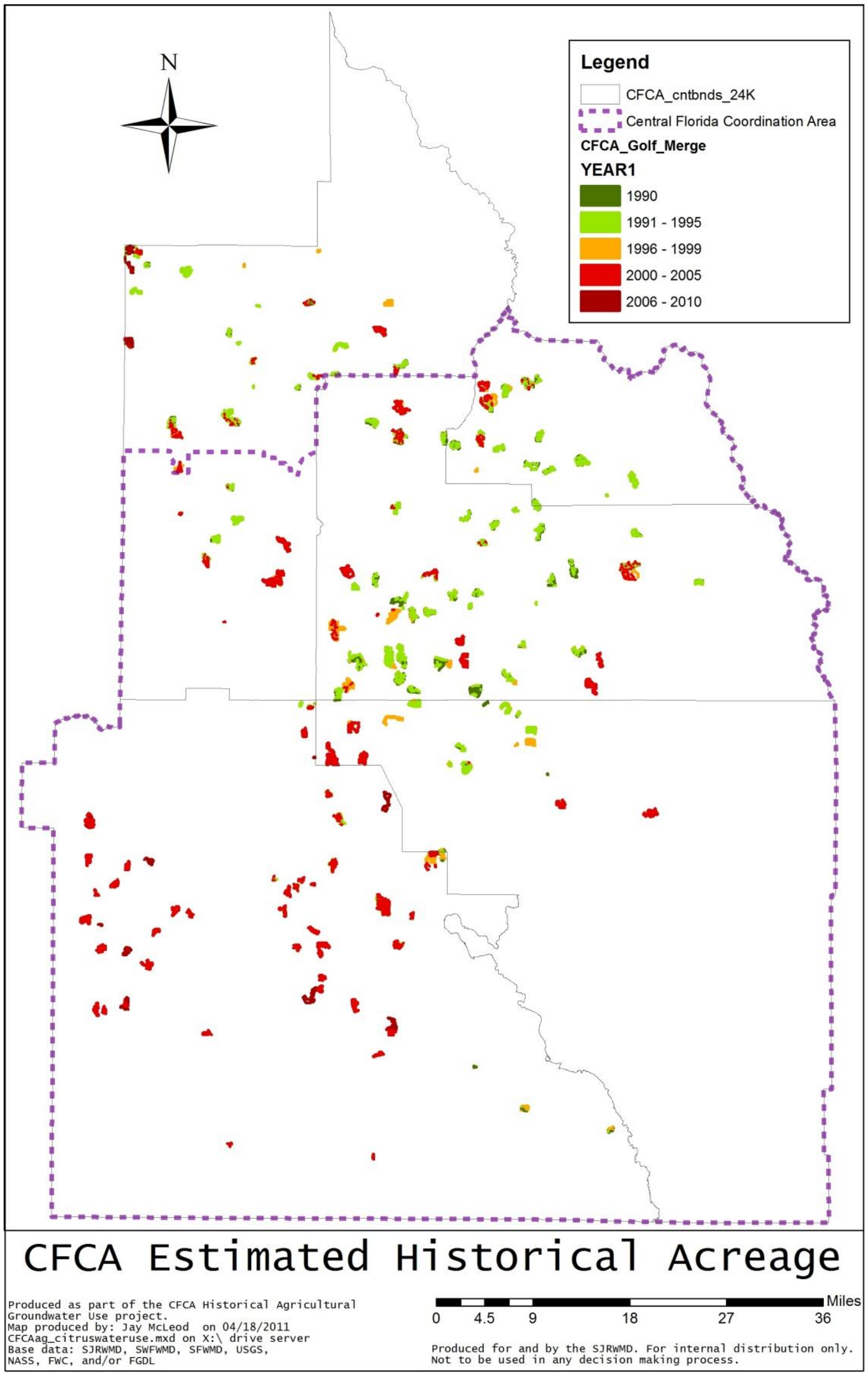

Figure 12. Estimated relative distribution of historical golf course acreages (areas exaggerated for display purposes)

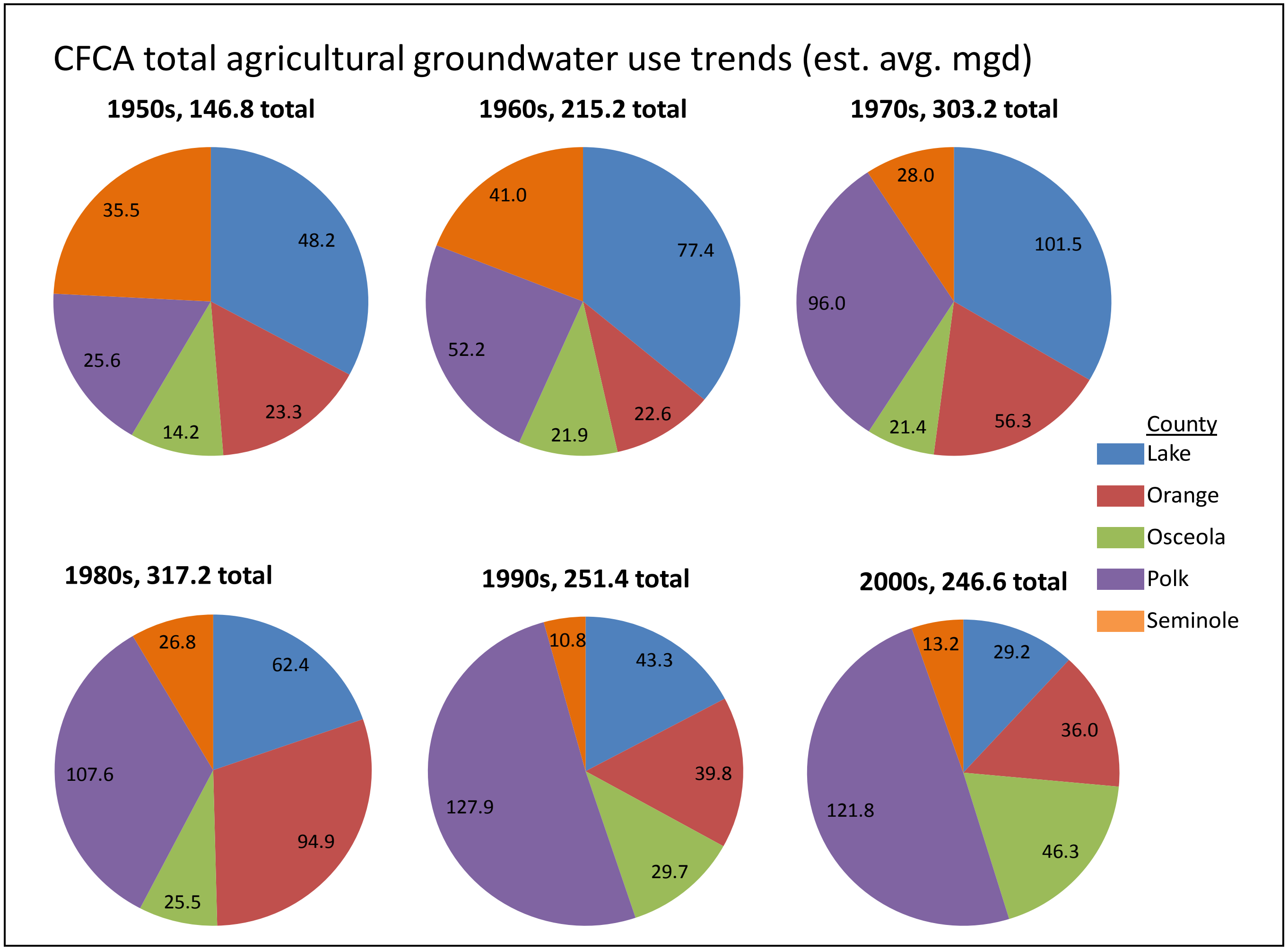

Figure 13. Decadal trends and county distribution of total agricultural groundwater use in Lake, Orange, and Seminole counties

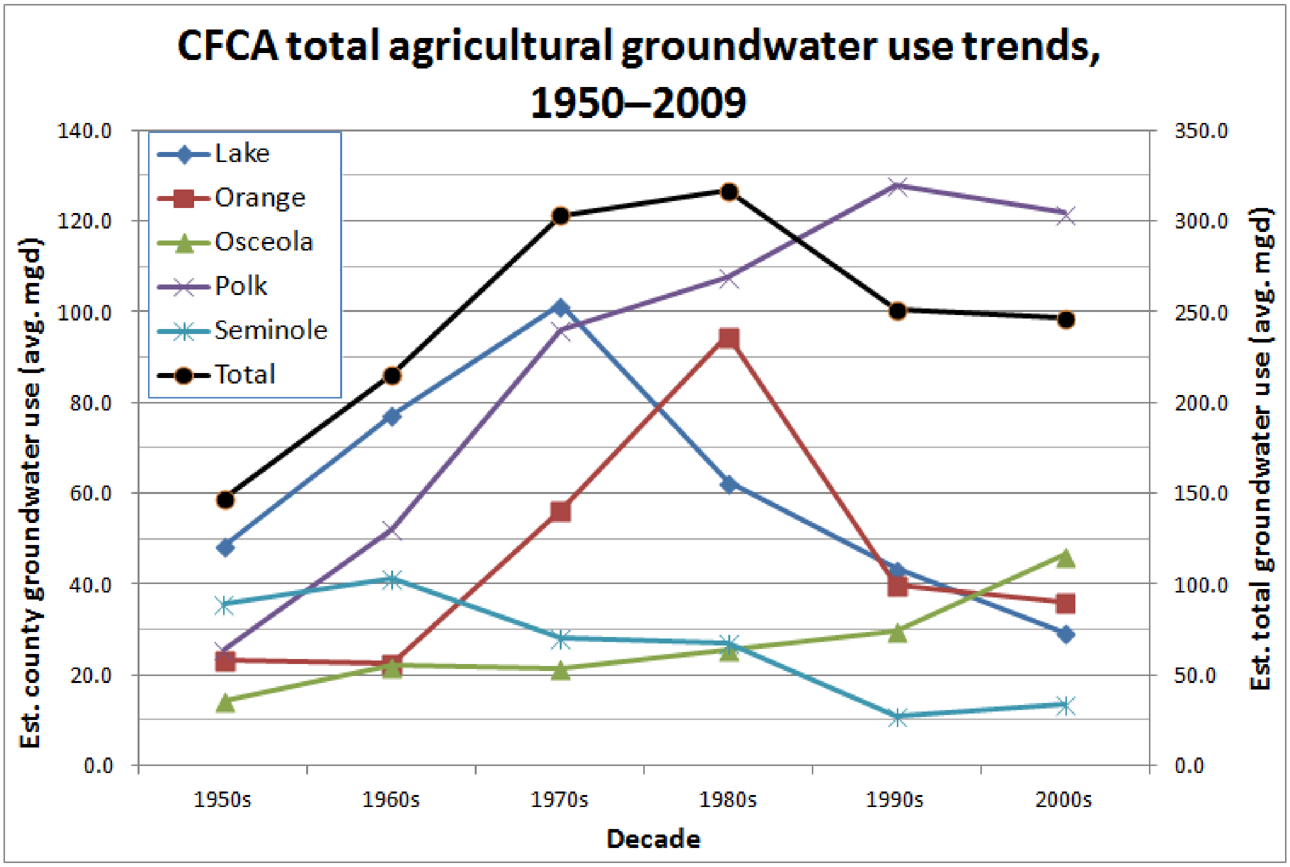

Figure 14. Trends of total agricultural (ag, citrus, and golf) groundwater use by county

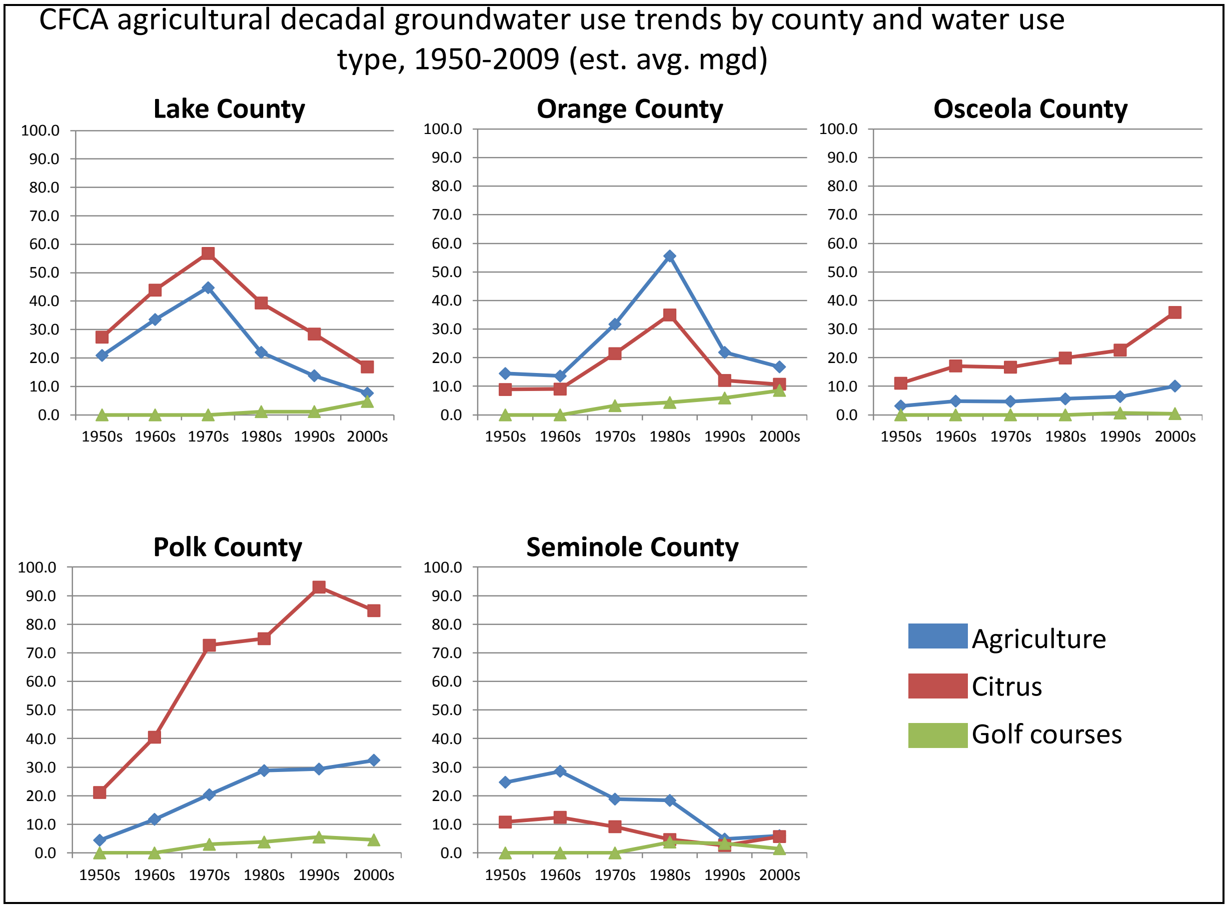

Figure 15. Decadal trends in agricultural groundwater use by county

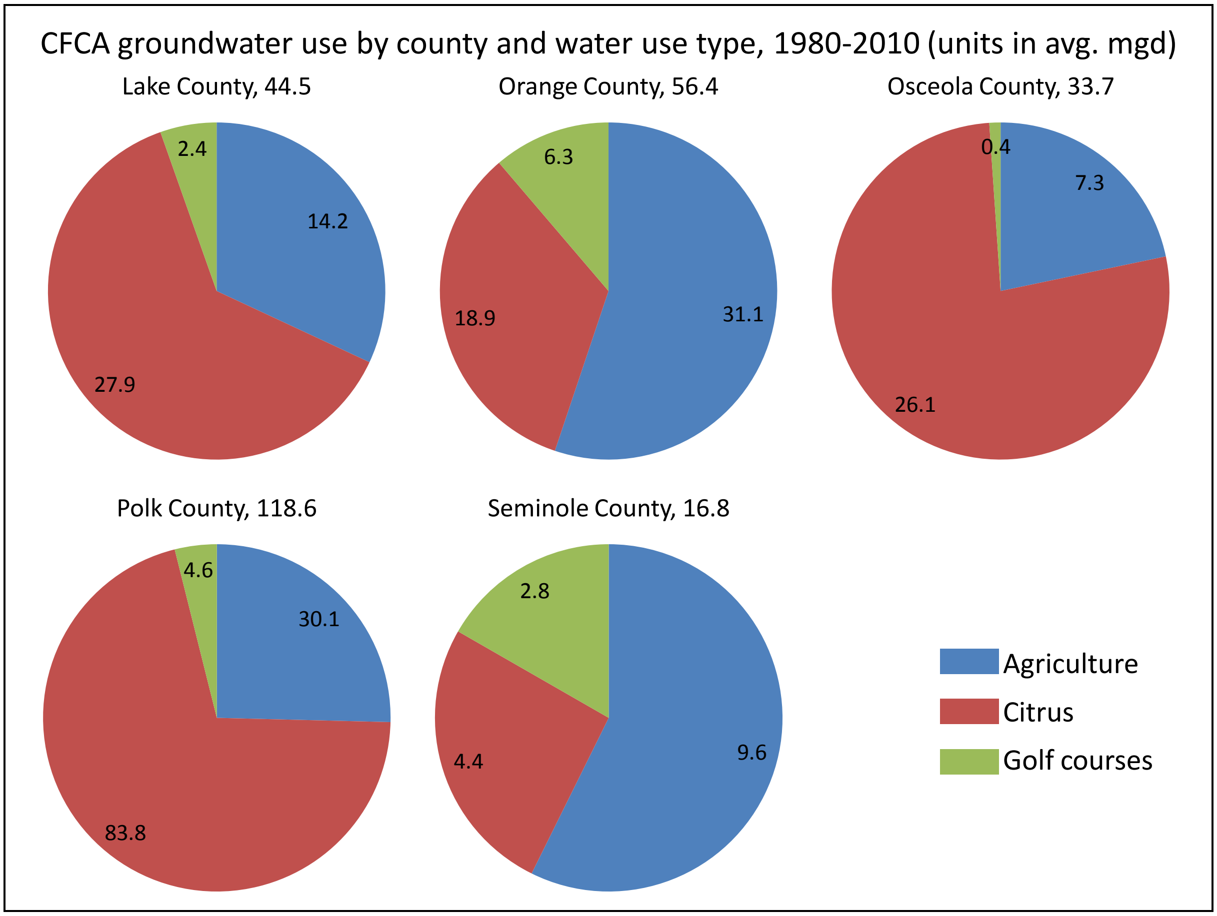

Figure 16. Average county total groundwater use

Table 12. Historical estimated annual groundwater use for each county by water use type, in mgd

Historical annual groundwater use estimates by water use type (in mgd).

	Lake County			Orange County			Osceola County			Polk County			Seminole County		
Year	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf
1957	14.10	18.44	-	14.66	8.98	-	2.12	7.53	-	6.16	19.89	-	18.67	8.15	-
1958	23.50	30.74	-	20.95	12.83	-	3.46	12.30	-	6.46	20.84	-	26.76	11.68	-
1959	25.07	32.79	-	7.77	4.76	-	3.74	13.31	-	0.69	22.67	-	28.75	12.54	-
1960	25.86	33.82	-	7.64	4.68	-	4.04	14.38	-	7.04	22.74	-	30.66	13.38	-
1961	27.42	35.86	-	11.31	6.93	-	4.33	15.42	-	7.04	22.74	-	32.68	14.26	-
1962	28.99	37.91	-	11.14	6.82	-	4.63	16.48	-	7.34	23.68	-	34.82	15.19	-
1963	32.12	42.01	-	7.71	5.64	-	5.15	18.33	-	7.63	24.63	-	36.54	15.94	-
1964	25.86	33.82	-	9.38	5.75	-	4.19	14.91	-	20.02	42.19	-	27.33	11.93	-
1965	32.12	42.01	-	9.31	8.76	-	4.01	14.27	-	9.01	42.33	-	19.18	8.37	-
1966	38.39	50.21	-	18.80	11.52	-	5.31	18.90	-	16.73	54.00	-	25.44	11.10	-
1967	39.96	52.26	-	19.28	11.81	-	5.40	19.21	-	17.90	57.79	-	25.52	11.14	-
1968	41.53	54.31	-	21.73	13.31	-	5.50	19.55	-	19.08	61.58	-	27.32	11.92	-
1969	43.09	56.36	-	19.52	14.83	-	5.54	19.70	-	5.76	53.09	-	26.18	11.42	-
1970	44.66	58.41	-	10.77	11.73	-	4.48	15.95	-	21.43	69.16	-	25.10	10.95	-
1971	44.66	58.41	-	23.61	14.46	-	5.38	19.12	-	22.16	71.53	-	24.25	10.58	-
1972	43.88	57.38	-	21.91	13.42	-	5.17	18.39	-	22.89	73.89	-	23.34	10.18	-
1973	45.44	59.43	-	24.79	15.18	-	5.13	18.26	-	23.77	76.74	-	21.66	9.45	-
1974	46.23	60.46	-	15.18	13.84	-	3.94	14.03	-	15.04	71.95	-	19.98	8.72	-
1975	46.23	60.46	-	16.11	17.93	-	4.13	14.70	-	21.26	78.50	-	19.23	8.39	-
1976	47.01	61.48	-	39.54	24.22	-	5.11	18.17	-	21.10	79.06	-	18.54	8.09	-
1977	46.24	62.51	-	39.35	30.00	-	3.66	13.02	-	20.42	78.20	2.96	18.08	7.89	-
1978	39.05	47.83	-	63.69	35.98	3.40	4.63	16.47	-	19.10	72.96	2.96	11.44	6.74	-
1979	43.77	41.40	-	61.98	37.35	3.03	5.24	18.62	-	16.50	54.53	3.08	6.62	10.73	-
1980	8.67	56.22	1.15	48.34	40.12	2.86	3.86	13.73	0.00	11.66	40.90	3.20	13.54	5.14	3.70
1981	15.09	61.68	1.15	79.34	45.01	3.11	6.25	22.22	0.00	26.22	91.09	3.32	14.95	5.12	3.70
1982	32.40	52.32	1.15	77.63	45.27	3.30	6.08	21.64	0.00	18.47	39.35	3.44	19.34	7.60	3.70
1983	31.17	52.89	1.15	73.92	48.16	4.30	5.88	20.90	0.00	30.98	44.49	3.56	25.24	7.56	3.70
1984	34.59	52.20	1.15	70.14	47.61	4.48	5.65	20.10	0.00	41.02	68.03	3.69	25.50	5.99	3.70
1985	18.49	10.29	1.12	33.78	25.82	4.78	9.08	32.29	0.00	28.35	85.26	4.06	18.10	5.11	3.70
1986	16.10	17.69	1.27	47.27	23.94	5.34	4.29	15.24	0.00	41.45	92.84	4.25	20.03	5.11	4.69
1987	18.11	33.77	1.17	40.21	22.13	4.92	4.27	15.18	0.00	22.57	66.24	4.25	18.92	1.75	3.76
1988	20.44	27.65	1.00	35.80	22.63	4.77	5.07	18.03	0.00	33.65	114.46	4.25	17.06	1.64	3.27
1989	24.71	28.60	1.09	49.37	28.75	5.50	5.46	19.41	0.00	33.61	106.75	4.25	10.90	1.80	4.06
1990	25.49	19.12	1.23	28.83	9.09	5.21	9.54	33.92	0.28	24.09	95.92	4.44	9.50	1.69	2.73

Table 12—*Continued*

Year	Lake County			Orange County			Osceola County			Polk County			Seminole County		
	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf	Ag	Citrus	Golf
1991	21.84	38.45	1.27	25.56	12.72	5.71	5.68	20.19	0.69	28.67	95.45	5.20	8.22	1.56	4.02
1992	13.69	26.38	0.55	26.05	14.74	4.28	5.90	20.97	0.68	17.87	94.18	5.20	4.06	1.55	1.47
1993	14.40	26.00	1.35	20.96	12.23	5.81	5.74	20.41	0.67	29.56	87.79	5.20	4.90	1.65	4.01
1994	14.77	27.65	1.35	20.07	12.50	5.84	5.86	20.83	0.67	29.68	83.45	5.20	3.64	3.01	3.98
1995	9.64	26.39	0.86	19.50	13.30	5.44	9.03	32.10	1.05	25.06	80.45	5.96	6.44	3.01	2.46
1996	8.91	29.48	1.23	21.03	12.27	6.19	5.50	19.56	0.63	36.63	94.86	5.96	2.88	3.37	3.46
1997	9.84	26.55	1.16	18.75	10.53	6.40	5.19	18.45	0.61	31.67	93.56	5.96	3.77	3.25	3.83
1998	11.96	42.46	1.56	26.42	13.96	7.50	6.07	21.58	0.59	31.73	100.64	5.96	3.38	4.26	4.34
1999	7.01	21.61	0.95	11.44	8.99	6.59	5.21	18.52	0.57	38.50	103.57	6.28	1.74	2.63	2.84
2000	17.66	16.22	4.54	12.43	10.11	14.28	8.56	30.43	0.54	49.70	129.31	8.09	6.28	5.74	6.74
2001	7.59	19.58	5.14	10.98	7.80	8.14	9.59	34.10	0.52	46.08	107.65	6.13	3.25	3.08	1.04
2002	6.31	16.64	4.35	9.75	7.36	7.79	7.31	26.01	0.50	36.55	103.81	4.60	2.30	2.19	0.95
2003	4.81	12.79	4.27	11.28	8.00	8.36	9.32	33.14	0.48	27.05	71.78	3.62	9.67	9.19	1.21
2004	5.56	14.70	5.75	12.34	8.69	7.61	9.81	34.88	0.46	28.22	76.59	2.48	12.60	11.96	0.72
2005	4.32	11.04	3.78	16.24	11.89	7.72	17.59	62.55	0.43	17.26	47.05	3.72	4.30	4.09	0.66
2006	7.31	19.09	5.99	22.35	13.47	7.67	18.28	65.03	0.41	32.52	86.58	4.07	4.82	4.57	1.25
2007	8.33	21.49	4.80	29.77	16.34	7.96	7.26	25.83	0.39	32.76	83.70	4.67	6.71	6.38	1.15
2008	6.92	17.86	4.76	20.34	12.63	7.82	6.46	22.98	0.37	26.78	68.73	4.43	4.67	4.43	0.57
2009	7.44	19.22	3.73	22.27	10.78	8.27	6.57	23.35	0.35	27.52	72.32	3.96	5.86	5.57	0.54
2010	6.94	17.94	4.61	21.70	10.51	8.53	6.83	24.28	0.32	27.49	72.35	3.96	5.27	5.01	0.83

Table 13. CFCA aggregate total estimated groundwater use, 1957–2010

CFCA total agricultural (ag, citrus, golf) estimated groundwater use, 1957–2010		
County	**billions of gallons**	**acre feet**
Lake	1,180	3,621,627
Orange	919	2,821,783
Osceola	542	1,663,503
Polk	1,858	5,700,543
Seminole	469	1,439,282
Sum	**4,968**	**15,246,738**

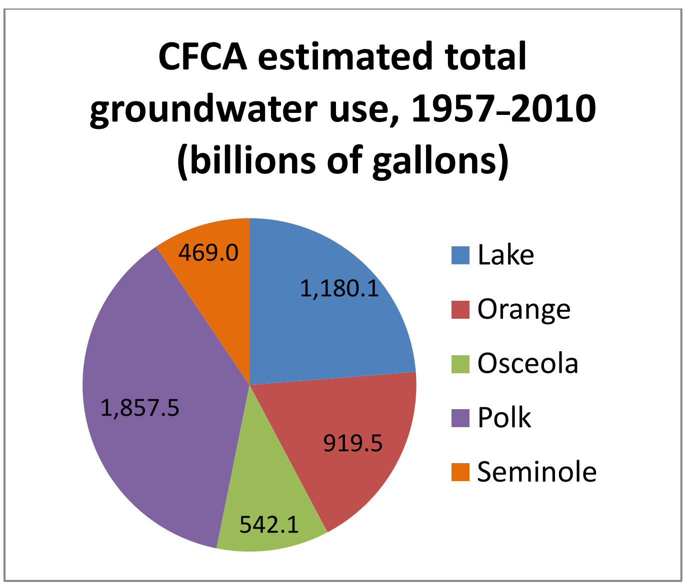

Figure 17. Through the entire time period, Polk County used the most total agricultural groundwater, followed by Lake and Orange counties

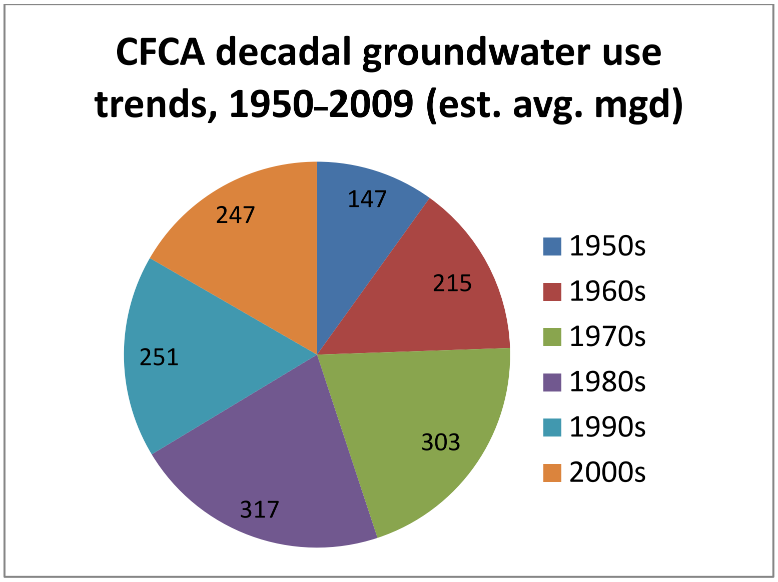

Figure 18. Total ag water use peaked in the 1970s and 1980s, but still maintains large withdrawal levels in present-day

ESTIMATED AGRICULTURAL GROUNDWATER USE BY CATEGORY

Other Agricultural Crop Estimates

Figure 19 displays the general trends in estimated agricultural groundwater use in the CFCA. Agricultural total groundwater use peaked in the early 1980s and has declined to roughly half of its historical high in present-day. Lake County trended toward less agricultural groundwater use following a peak value in 1979, while Orange County contributed to most of the groundwater use in the early 1980s. Osceola County has never been a significant contributor to agricultural groundwater use, while Polk County has trended toward increased groundwater withdraws throughout the time period of this project. Once again, this displays a general trend toward a southward movement of agriculture during the time period from the early 1980s to present-day.

Citrus Groundwater Use Estimates

Figure 20 shows that although overall groundwater use has remained relatively constant from 1967 through 2010, there was a decrease in citrus groundwater use in Lake, Orange and Seminole counties in 1985. Conversely, Polk County shows an increase in citrus groundwater use from that time period moving forward to present. This corresponds well with the spatial citrus acreage estimates generated in this project, as well as reports of general citrus grower migrations southward following the impact freezes of the late 1970s and early 1980s.

Golf Course Groundwater Use Estimates

Groundwater withdrawal data for golf courses was generally only available from 1980–2010 for all counties. Polk County data could be estimated back to 1977, and Orange County could be estimated back to 1978. Osceola County was only able to be reliably estimated from 1990 to present, and so the time period from 1980–1989 must be estimated at zero, although it is likely that some golf courses were developed during this time frame. From Figure 21, the general trend is of increasing total golf course groundwater withdrawals throughout the CFCA, primarily being driven by Orange, Polk, and Lake counties, with Lake County only contributing very significantly in the past10 years.

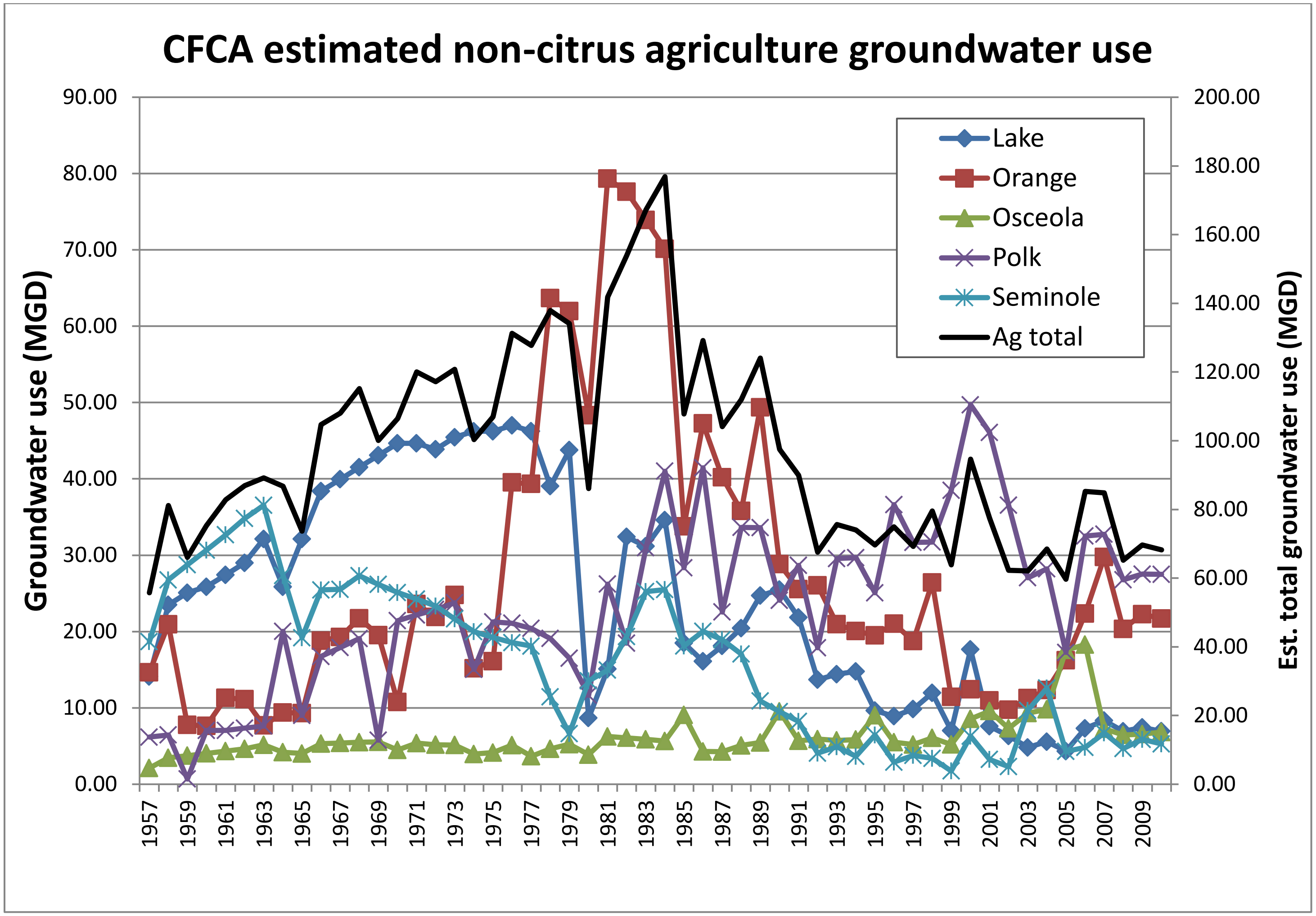

Figure 19. Historical estimated annual non-citrus agricultural groundwater use by county (1957–2010)

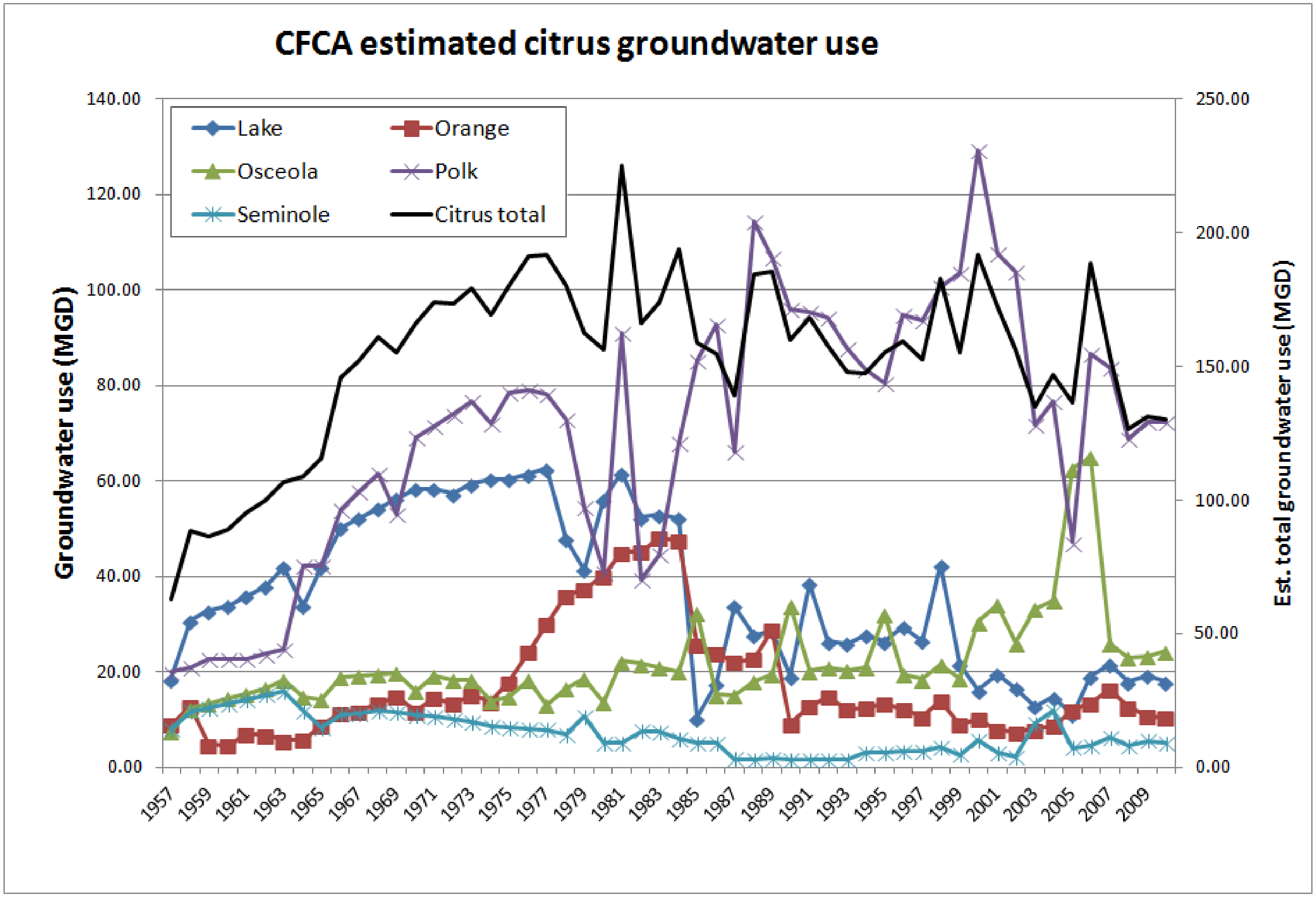

Figure 20. Historical estimated annual citrus groundwater use by county (1957–2010)

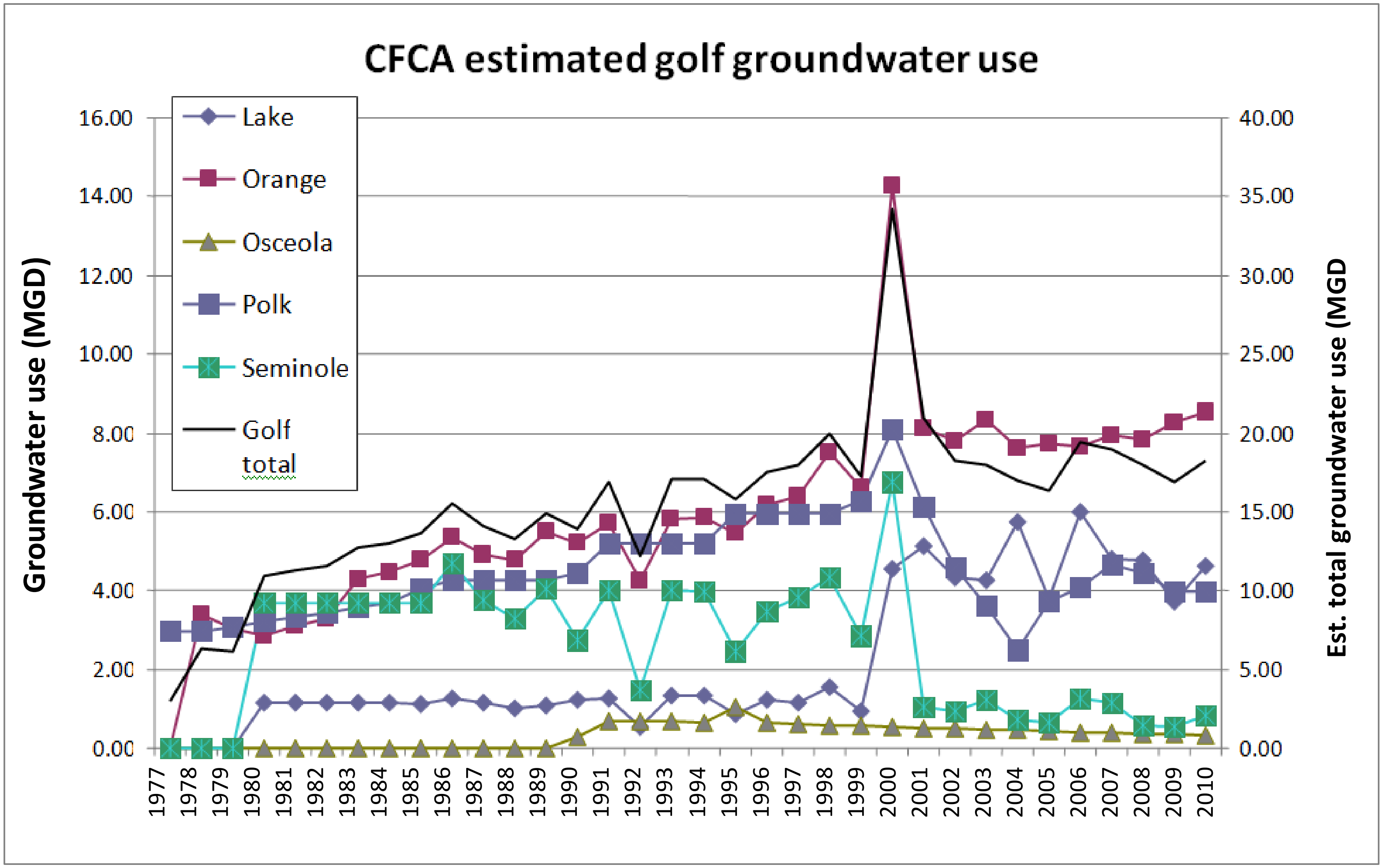

Figure 21. Historical estimated annual golf course groundwater use by county

CONCLUSIONS

The final data set generated in this project reasonably approximates known groundwater use trends in the region during this time period, including the shift of citrus production southward following heavy freezes, the displacement of agriculture during periods of urban infrastructure expansion, and the expansion of golf course acreage concurrent with expanding urban development. Due to the proportional nature of the attribution of groundwater use based on area of each estimated polygon relevant to all other polygons for each year, it is important to remember that only estimated groundwater use is accurate, and not acreages, at a large spatial extent. Since the ANN will utilize regional, multiyear groundwater use trends to determine outputs and linkages, this is sufficient. Temporally, the groundwater use estimations are most accurate from roughly 1977 to 2010, while the spatial acreage delineations are most accurate from 1985 to 2005 or 2010, depending on the county.

Refinement of the public lands temporal exclusion portion of this project (via the "year established" field) represents a significant opportunity to refine the final data set. The more precise knowledge of when public lands were purchased and protected the better their exclusion from agricultural, citrus, and golf acreage delineation will reflect reality.

Acquisition or creation of a land use/land cover data set from the late 1970s, late 1950s, or any year in the 1960s would represent a significant addition to the historical distribution of acreages. This would definitely refine the historical acreage distribution of more historical years. Additionally, an updated NASS data set that covers all of the counties in the CFCA would greatly increase the accuracy of groundwater use distribution in years close to present-day.

The refinement of the groundwater use estimations could be achieved through a variety of ways. There was a noticeable absence of very accurate historical groundwater use data from the SFWMD for almost the entire time span of this project. The creation or addition of data for the SFWMD would greatly enhance the estimations for that part of the CFCA. Additionally, any data for the SJRWMD or SWFWMD from years around the mid-1970s to the beginning of this project (1950s) would enhance the overall groundwater use estimations as well.

The accuracy of the monthly distribution of water use could be enhanced by a historical analysis of crop types by county and historical irrigation schemes, or perhaps historical climatic data. Even a decadal estimation of predominant crop types could lead to a refinement of the monthly irrigation distribution that might affect the overall picture. However, since this project focuses on large-scale trends in groundwater use, the knowledge that most watering comes in spring, followed by a secondary large application in fall, is likely sufficient to provide a satisfactory analysis. The accuracy of groundwater use distribution could be enhanced with a more comprehensive knowledge of the irrigation types and sources employed by each farm on each parcel. This level of detail would require significant research into historical records, and was definitely beyond the scope of this project. However, a large-scale knowledge of water source would greatly refine the spatial signature of the final data set.

Although an easy, but time consuming, way to increase the accuracy of the golf course spatial delineation data would be to determine the establishment date for each golf course. By cross-referencing the ArcGIS map with an online mapping resource, such as Google Maps (*www.maps.google.com*), it is possible to synchronize the location of certain golf courses, and determine the name of the course. Using both the map view and the satellite view in Google Maps facilitates this process. Then accessing the "course finder" on Golf.com it is possible to search for each golf course individually by name. Generally, the information section of each golf course includes a year established. This information could be added to the ArcGIS map to create a more accurate spatial map, with respect to the temporal distribution of golf courses. Another method for identifying golf courses and other agricultural type lands would be to compare the FLUCCS data to current (and historical) county property appraiser data based upon The Department of Revenue Land Use Codes. However, the availability of this historical information could be an issue.

Additionally, since improved pastureland irrigation practices were not well known at the time of this project, they were not included in the final data sets. It is tempting to assume that improved pasture grasses would have irrigation patterns similar to golf course turf. However, golf course grasses are usually shallow rooted, while pasture grasses are usually more deeply rooted. This physiological difference would probably provide enough difference in irrigation regimes that they could not be assumed to be the same. Further exploration into this subject would refine the overall groundwater use estimates presented herein.

Public lands, state of Florida parklands, and other publicly managed or held areas were removed from possible land areas during the determination of spatial distribution of each water use type. Some of the public or managed lands used in this GIS analysis did not have data available for their date of establishment. Since citrus or agriculture could have been cultivated previously on current-day public lands prior to their being given into the public trust, further refining and understanding when each public park or managed land was established could lead to a spatial refinement of the final data set.

This project and the data sets created herein for the ANN models represent a large step toward accurately estimating historical groundwater use in the CFCA. These GIS models, in a sense, are "living" and repeatable with newer, more accurate data sources when available. Full knowledge of the inner workings, assumptions, and limitations of this project will allow its incorporation into the USGS Data Mining Project. Further refinements to the results of the findings presented here may lead to the refinement of the ANN project. However, subtle variations from the broad trends presented here will likely have little effect on the overall outcomes of the ANN, since agricultural, citrus, and golf course groundwater use are but one subset of many other inputs used in the ANN.

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MEMORANDUM

METHODOLOGY FOR ESTIMATING HISTORICAL AGRICULTURAL GROUNDWATER USE IN THE CENTRAL FLORIDA COORDINATION AREA (CFCA) 1957–2010

Date: May 30, 2012

Division: St. Johns River Water Management District, Division of Water Resources

Project: USGS Data Mining project, CFCA Historical Groundwater Use Estimation.

Authors:
Jay McLeod (October 20, 2010–May 5, 2011)
Doug Munch (May 2011–April 2012)

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1. GIS

Directly associated GIS ArcMap and ArcToolbox files (access through ArcMap or ArcCatalog):

- CFCAag_citruswateruse.mxd
- CFCA_1prep_steps.tbx
- CFCA_citruswateruse.gdb
- CFCA_LakeCo.tbx
- CFCA_OrangeCo.tbx
- CFCA_OsceolaCo.tbx
- CFCA_PolkCo.tbx
- CFCA_SeminoleCo.tbx

2. Supporting Information

Complementary and supporting procedural and base information:

- CFCA Ag Water Use Model Flowchart.pptx
- CFCA_data_coverage_by_source
- CFCA_wateruse_data_accuracy
- Copy of Historical AG-REC Water Use 1978-2009_BruceFlorence
- FASSData_SWFWMD
- FLMAs_w_year_201101
- GISposter_JM3
- ProjectCompletionChecklist

- ARGY95
- SeminoleCo_data problems 100610
- Water source data comparison 101410

3. Water Use Data

Directly incorporated annual water use and monthly distribution information:

- AgWaterUse_AnnualDistr
- CitrusWaterUse_AnnualDistr
- GolfWaterUse_AnnualDistr
- CFCA_all_wateruse_rawdata
- Lake_Ag_waterusedata
- Lake_Citrus_waterusedata
- Lake_Golf_waterusedata
- Orange_Ag_waterusedata
- Orange_Citrus_waterusedata
- Orange_Golf_waterusedata
- Osceola_Ag_waterusedata
- Osceola_Citrus_waterusedata
- Osceola_Golf_waterusedata
- Polk_Ag_waterusedata
- Polk_Citrus_waterusedata
- Polk_Golf_waterusedata
- Seminole_Ag_waterusedata
- Seminole_Citrus_waterusedata
- Seminole_Golf_waterusedata

4. Auxiliary information

- AGRICULT LND PROJECTIONS
- CCI06
- Citrus freeze protection methods
- Florida Citrus Freezes timeline
- Schelske et al. 2005 (Ambio - Apopka)

APPENDIX A: ASSUMPTIONS

There are many assumptions present in the models created for this project, and in the calculations used to estimate historical groundwater use. A list of major assumptions specific to this project appears below. Although this list may not be exhaustive, it will familiarize the reader with some of the major limitations involved with the scope of this project.

MAJOR ASSUMPTIONS

1. Although the USGS Data Mining project was initially concerned with only the portion of each county within the CFCA, this study utilized and estimated data for the entirety of each county that is part of the CFCA (Lake, Orange, Osceola, Polk, and Seminole). This facilitated data processing and did not negatively affect the final product data sets. Throughout this study, when referring to the CFCA or the CFCA counties, the data being presented is for the entire county, and not just the portion within the CFCA. This is especially pertinent for Lake County.
2. Due to the uncertainty associated with accounting and field practices associated with pasture irrigation, it was assumed not to be a large factor in the overall water use patterns or trends within the study area.
3. All citrus (or agricultural land) that is presently active has always been active, and is considered to be in areas that are conducive to cultivation. New citrus or agricultural polygons are generally delineated in and near these areas.
4. Every year, historical or recent, is a “normal” year for rainfall, and irrigation is delivered proportionally based on monthly requirements.
5. Every polygon receives an amount of irrigation according to its proportional amount of the total annual area, calculated from all polygons for that time period. This assumes that all acreages are irrigated identically, and an even distribution of irrigation water. This provides a coarse groundwater use estimate that assumes a large amount of similarity in management and resource access between all polygons.
6. Monthly distribution of water use is determined with an unweighted average of common crop types and/or irrigation regimes. This is converted to proportional monthly water use, such that the water use from all months in a year sum to one.
7. Every month contributes greater than zero to the proportional annual water use.
8. Irrigation and water use is contributed to in equal proportions each month, independent of source. So monthly groundwater use is the same percentage of total water use, and does

not change monthly regardless of surface water reservoir levels, for every month of the year.

9. Any decrease in citrus (or agricultural) acreage moving backward through time assumes that the more historical (lesser) acreage of citrus is physically located (contained) within the greater (closer to year 2010) spatial acreage estimate. Accordingly, differences in irrigation because of lesser acreages will be accounted for with lower groundwater use estimates, which will be spatially distributed, based on proportional area of polygons. In some cases, if acreages "shrink" moving backwards, they will not be reduced because since these estimates will be used regionally, it is assumed that the larger acreage will encompass the reduced acreage and that water distribution will be similar. This generally represents the notion of creating a cone of uncertainty that becomes larger approaching early periods. This is not uncommon when estimating historical events, and should generally avoid the occurrence of false positive results (i.e., results that would create localized anomalies).
10. Whenever a raster format is converted to a polygon during historical delineation, any resultant polygons with area less than 2 acres (8093 square meters) are deleted. This is to avoid having "slivers" that result from conversion from raster to polygon, and may artificially skew the distribution.
11. Only polygons with area greater than one-quarter acre (0.25 acre) identified during the delineation of historical citrus or agricultural areas will be kept. This is also to avoid "sliver" skewness.
12. Any area that was ever historically citrus never became agricultural land, as we approach present-day. Citrus and agriculture are distinct, non-overlapping areas.
13. Golf courses are easily and accurately delineated from aerial imagery, no matter what the time period (i.e., no mistakes were made when delineating golf courses from aerial imagery).

APPENDIX B: DATA SOURCES, LOCATION, AND FILE STRUCTURE

ACCEPTABLE DATA SOURCES

These data sources were used for historical acreage delineation, historical groundwater use estimation, and determination of monthly water use distribution. The following data was deemed acceptable in quality and coverage, and is derived from reputable sources.

- National Agricultural Statistics Service (NASS) Commercial Citrus Inventory (CCI) reports and GIS Shapefiles (Active_10, and Inactive_10) from Florida Agricultural Statistics Service (FASS) branch
- U. S. Geological Survey (USGS) (water use surveys)
- St. Johns River Water Management District (SJRWMD) Annual Water Use Survey
- South Florida Water Management District (SFWMD) Water Supply Plan (WSP)
- Southwest Florida Water Management District (SWFWMD) Water Use Reports (WUR)
- Any water management district (WMD) Land Use/Land Cover (LULC) GIS data
- USGS LULC GIS data
- LULC data obtained from Florida Geographic Data Library (FGDL) (www.FGDL.org)
- Florida Fish and Wildlife Conservation Commission (FWC) LULC GIS data
- Natural Resources Conservation Service (NRCS) Florida Supplements to National Engineering Handbook (NEH) (at *ftp://ftp-fc.sc.egov.usda.gov/FL/flengforms/nehfl652ch_4.pdf*)

DATA LOCATION OVERVIEW

Although data has been assembled from multiple sources, all the data and processes necessary to run these models and create the GIS data is contained in three locations on the SJRWMD server (and can be accessed by the public on CD, available through the SJRWMD Scientific Reference Center).

1. The SJRWMD Arc.SDE server files (EARTH server), accessed through the SJR Citrix icon/toolbar in ArcMap. Generally, the files found here are base data and/or constraining political boundaries or features.
2. The CFCA_citruswateruse.gdb geodatabase, which contains:
    a. The ArcMap (.mxd) file CFCAag_citruswateruse.mxd, which contains data, layers, and models for all model types (citrus, agriculture (i.e. non-citrus agriculture), and golf course)…(unfortunately, it will break too many links to rename it something without the word “citrus”).

b. The groundwater use estimate tables (which describe monthly groundwater use for each polygon in average gallons of groundwater per day, by month) that are used to populate the final product GIS files of these models are created in model step 3 of each model (suffixed "_s3," see below) are created in model step 3 and are stored in the geodatabase as well. They can be accessed through ArcCatalog. These .dbf tables are created in model step 3 from MS Excel files stored in the folder described below (#3).

c. The final product GIS files created by these models are stored in the feature data set named for the appropriate county in this geodatabase, and can be accessed through ArcCatalog. They are labeled as such: [County abbreviation]_[use type]_s3f. So, Seminole County citrus water use data is contained in "Sem_citrus_s3f," Seminole County agricultural (non-citrus) data is contained in "Sem_ag_s3f," and Seminole County golf course water use data is contained in "Sem_golf_s3f". The "_s3f" suffix is merely an internal naming convention that denotes this data comes from model step 3 and is final (hence "_s3f").

3. The folder CFCAag_wateruseworkfilesALL contains the ArcToolbox (.tbx) files that house the models and are accessible via the .mxd file (Item 2a, from Appendix C). Also in this folder are the historical groundwater use estimate MS Excel files that create the .dbf tables (item 2b, in Overview, above).

   a. The ArcToolbox files that contain the models used to create the final files are labeled by "CFCA_[county]Co" (ex- "CFCA_SeminoleCo.tbx" houses the all the models used for Seminole County). Within each model (accessed through ArcMap), there are three separate models for each ag (non-citrus agriculture), citrus, and golf (courses) groundwater use.

      i. NOTE 1: the suffixes "_s1," "_s2," and "_s3" denote steps 1, 2, and 3 in the processing of data, and they should be run in that order (i.e. Seminole_citrus_s1 model should be run first, then Seminole_citrus_s2 model, and then Seminole_citrus_s3 model, which creates the final data layer). More detailed descriptions of processes in these models are documented elsewhere in this document.

      ii. NOTE 2: The models in "CFCA_1prep_steps.tbx" should be run preceeding the running of all county's models, but only need be updated and run once. The models in CFCA_1prep_steps.tbx create supplementary files that are used to create the final products for each county

   b. MS Excel files used to generate the historical groundwater use estimates (from item 2b in Overview, above) are also stored in this folder. They are utilized in model step 3 for each county for each water use type. They are named by "[county]_[water use type]_waterusedata.xlsx" (ex- Seminole_Ag_waterusedata.xlsx contains the annual and monthly groundwater use estimates for Seminole County agriculture (non-citrus)) and contain the data for all years covered in this project. Any changes to information regarding historical groundwater use estimates should occur on these files.

NOTE: Items 2 and 3 (from Overview) are stored in X:\GWP\Users\CFCA_HistoricalWaterUse. Other files stored in that folder location are maintained only as relics of previous interns' work. Those files have been culled down to the most useful and/or most relevant, which are recopied or stored in items 2 and 3, as listed above.

SUBFOLDERS OVERVIEW

The following subfolders are in CFCAag_wateruseworkfilesALL (Item 3, from Data location overview) and are loaded to CD separate from this report:

1. Temp contains working GIS files and .dbf that are created as intermediates when running the models. These files should update, replace, and/or recreate themselves automatically when the models are run in the proper order. However, it may be preferable to simply delete all elements in this folder when running different county or water use type models.
   a. The .dbf files that are created near the end of model step 2 (the "_s2" models in each county .tbx) contain annual acreage information for each polygon designated as present in each year. They need to be opened from Excel (as a .dbf, using Open, and checking "all files"), and copy-and-pasted into the second page of the appropriate Excel workbook (named "workdataallyrs"), starting at column labeled "fid1," and continuing to "p1957," "p1958," etc. (Be sure to erase the "Frequency" column before executing the copy-and-paste, so that the columns line up properly).
2. CFCA Model Tables contains a copy of the .dbf tables created at the end of each model step 2, that are used to populate the "workdataallyears" in the appropriate Excel files (1a in Subfolders Overview, above). They are saved here as .dbf, and they also exist in duplicate form within the geodatabase.
3. CFCA_Finalfiles contains the final GIS products from this project, which have been manually saved separately as shapefiles.
4. USGS water use data contains good water use estimates, mostly Excel files, obtained from Bruce Florence (SJRWMD), and stored in his office on CD. The most relevant data has been copied to this folder. There are a lot of files, so you just have to go through them until you find useful data.
5. FGDLdata contains GIS files obtained from www.FGDL.org for land use/land cover for specific counties in the CFCA.
6. SFWMD_data contains data that may not be relevant or useful, but was compiled and saved anyway.
7. SWFWMDdata contains a land use/land cover GIS file for 1990, that is probably already imported into the geodatabase.
8. NASS Citrus data in SJRWMD contains the files Active_10 and Inactive_10 that are from NASS, cover only the SJRWMD, and are used as a starting point in delineating GIS citrus polygons for the citrus models (see the model named Seminole_citrus_s1, in the CFCA_SeminoleCo.tbx, for an example).

9. USGSshapefiles from AndyOreilly contains the boundaries for the megagrid (used in Modflow, and probably not relevant to this project anymore) and some old land use/land cover data (which has already been imported into the geodatabase.
10. Favorites, put in Internet Explorer to access data sources contains the Internet Explorer (IE) favorites files that have been used for data acquisition for this project. To utilize them, copy-and-paste these files into the IE favorites folder, and then access them through IE.
11. Additionally, there are some downloaded GIS files stored in subfolders.
    These are easily found at the Florida Geographic Data Library (located at *www.FGDL.org*) or at their respective sources. For instance, the National Hydrologic Database (NHD) water bodies files are in their own folder.

GEODATABASE DETAILED

The geodatabase CFCA_citruswateruse.gdb contains the following feature data sets:

1. **AFSIRS_grid**: which contains unused data showing the AFSIRS grid. This data was not used in the creation of the final data. This is a relic file.
2. **Backgrounddata**: which contains data like public lands, hydrological features, and political boundaries (Counties, CFCA, etc.).
3. **Imagery**: which would contain any imagery used in acreage delineation. No imagery was used in the creation of the final data. This is a relic file.
4. **LakeCo**: which contains final groundwater use GIS data relevant to Lake County.
5. **OrangeCo**: which contains final groundwater use GIS data relevant to Orange County.
6. **OsceolaCo**: which contains final groundwater use GIS data relevant to Osceola County.
7. **PolkCo**: which contains final groundwater use GIS data relevant to Polk County.
8. **SeminoleCo**: which contains final groundwater use GIS data relevant to Seminole County.
9. **LULC_basedata**: which contains land use/land cover data from various sources, usually from USGS, FGDL, and WMDs.
10. **NASScitrusdata**: which contains GIS data from NASS (Florida Branch), files Active_10 and Inactive_10, which were used as starting points for delineating citrus acreage in some SJRWMD counties.
11. **Oldfiles**: which contains relic files from intern Jennifer Kasper's work, and are not relevant to these models. Most of these have been deleted. The remainder must be individually checked for accuracy and relevance before they are used.
12. **USGSdata**: which contains land use/land cover GIS data from USGS files, which is used to guide the delineation of historical agricultural areas.

In addition, file geodatabase tables are created in step 3 (labeled with suffix "_s3" for the three water use types- citrus, agriculture, and golf) of each model, as the groundwater use estimates for each decade (described in Item 2, from Excel Files Overview) are joined to the GIS polygon feature class. These .dbf files are stored, as a record in the geodatabase under the name “[County name]_[use type][beginning year of the decade]s_wateruse”. So, groundwater use estimates, by unique polygon identification field (labeled “polyid” or “fid1”), for Seminole County citrus, years 1980-1989, would be called “Seminole_citrus1980s_wateruse”. Because these files are so large, they could only be joined with a decade of information at a time, and so they are recorded in a similar fashion. When information in the Excel file that generates these tables is updated, the portion of the model that creates them (in the appropriate “_s3” model) needs to be run manually, to replace these files in the geodatabase and provide an updated final product, GIS feature class.

APPENDIX C: MODEL STRUCTURE AND FUNCTION

MODEL OVERVIEW

These toolboxes and models were created within ArcGIS 9.3, using ModelBuilder, and are were saved on the SJRWMD server. See CFCA Ag Water Use Model Flowchart.pptx and GISposter_JM3 for additional information and graphical depiction, or examine the toolbox files from within ArcMap itself. The ArcToolboxes created in this project include CFCA_1_prep_steps, CFCA_LakeCo, CFCA_OrangeCo, CFCA_OsceolaCo, CFCA_PolkCo, and CFCA_SeminoleCo.

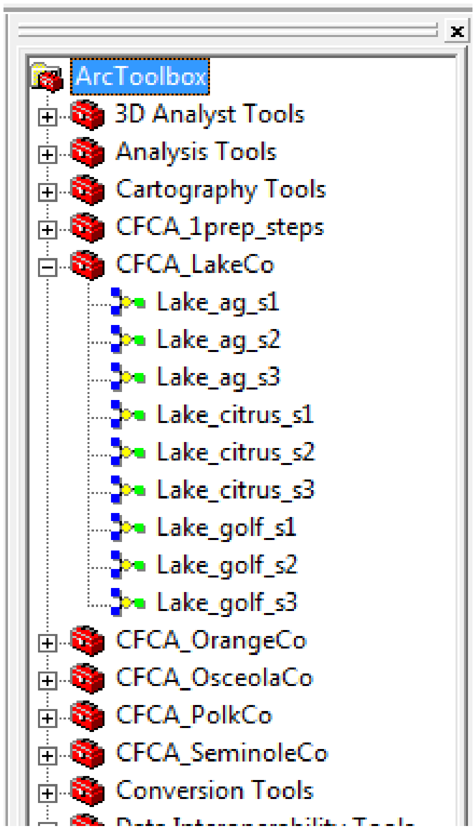


Figure C-1. Structure of the models, as housed within ArcToolbox, and opened from ArcMap

CFCA_1prep_steps.tbx contains data processing steps that were executed before the county-specific models were executed. This toolbox creates some data sets and stores them within the geodatabase. These data sets are used in the processing of the county-specific toolboxes. Generally, this set of models it is concerned with creating a CFCA five-county boundary, and clipping public lands and water body boundaries to the CFCA boundary, for the purpose of reduced processing time in processes executed in the county-specific models.

Within each county, there are three models, with three steps in each model. The models are named for the type of historical groundwater use they attempt to estimate: citrus, ag (non-citrus agriculture), and golf courses. The three steps in each model are labeled with the suffixes "_s1," "_s2," or "_s3" (Figure C-1). The three model steps for each land use type must be run in sequential order. Additionally, each county must have the citrus models run before the agricultural models. This is because citrus and agriculture are assumed to be non-overlapping, and the citrus is given priority in delineation, partially because it is a primary groundwater user in the CFCA.

CFCA_*1prep_steps toolbox*

This toolbox of models contains steps that are common to all of the subsequent county-specific models. In general, it creates and simplifies larger, often statewide, data sets that serve as parameters to the processes within the other county-specific models. The outputs of the models in this toolbox are stored in the geodatabase, and are accessed from there by the county-specific models. The models in the CFCA_1prep_steps toolbox do not need to be updated (i.e., run again) unless there is a change in the data involving county boundaries, hydrologic boundaries (i.e., water bodies), or public lands. The models within the toolbox are described below.

- **CFCA_countybnd.** This model merges the county boundaries for the counties that are part of the CFCA. This boundary is used in other models as a clipping feature.
- **Hydro_CFCA_prep.** This model clips a statewide hydrological file to the CFCA counties. The original file was too cumbersome to use in the county-specific models; this speeds up processing time.
- **Publand_CFCA_prep.** This model joins the statewide public lands layer, and clips it to the CFCA county boundaries. This is used throughout the county-specific models as a mask to exclude certain lands from the final data set. This data set could be updated (field: "yr_est") and significantly change the final data set.
- **water body bnds.** This model is related to the water bodies within the CFCA, and their exclusion from the final data set. After all, citrus, agriculture, and golf courses rarely spatially coincide with open bodies of water.

COUNTY-SPECIFIC MODEL STEPS OVERVIEW

1. **Model step 1 (denoted with "_s1")**: This step generally takes the raw or starting data and selects the parts that are relevant to the land use in question. The field "FID1" (field type: double) is added as a unique polygon identifier, and later in _s3 provides a common field for joining to the field "fid1" (or "polyid") from the Excel files that detail the monthly groundwater use estimates. Areas are calculated in internal units (sq. meters) in the field "AREA1" (field type: double) and in acres in the field "ACRE1" (field type: double). Also, 53 fields (labeled "p[year]"), from year 1957 to year 2010 (field type: double) are added to facilitate the extraction of annual acreage data, which will be used to calculate groundwater use estimates in between step 2 and step 3.
    i. NOTE 1: This step culminates in the saving of the data in a Temp file, because the batched field addition created unique difficulties in continuing model processes without first saving. The saved, final data is the starting point for model step 2, _s2.
2. **Model step 2 (denoted with "_s2")**: This step isolates each of the years that were batch-added at the end of _s1, and determines which polygons were present or absent based on our best historical land cover estimates. These are recorded as an acreage under the appropriate year field, which are preceded by "p" to accommodate ArcGIS internal naming convention restraints (i.e.- fields cannot start with a numerical character). The final processes in this step export a statistical summary of the data for incorporation into the Excel files, and saving the data in a Temp file. The last file in this model is suffixed "_s2f," and is the beginning step for model step 3.
    i. NOTE 1: The statistical summary table (a .dbf file) must be processed as follows <u>before</u> the next model step: open the .dbf file (located in the Temp folder) <u>from within</u> MSExcel, delete the column "FREQUENCY." Then copy the remaining data (excluding headers) and paste under the column "fid1" in the appropriate MSExcel file. This should fill in all data for "fid1" and all fields from "p1957" to "p2010" (or other, as appropriate). Copy the formulas down (highlight, then Ctrl+D) in "pct1957" to "pct2010" (which will recalculate themselves) until they account for all the data that was just pasted in (the fid1 and p1957 through p2010 data). Be sure to copy the formulas in the other worksheets ("wateruse1950s" through "wateruse2010s") down until they cover the number of polygons in "fid1". The data in the "wateruse[beginning year of the decade]s" worksheets will eventually be converted and joined (in model step 3) to the GIS data (created in model steps 1 and 2).
3. **Model step 3 (denoted with "_s3")**: The final step in the model deletes superfluous fields (such as might have been present in original data sources), and joins the groundwater use estimates (by month and year) from the Excel files into a final data set, which includes a county name field, "COUNTY" (field type: text). The groundwater use estimates are in average gallons of groundwater per day, by month, for each polygon, from 1957 through 2010. This file is saved in the appropriate county feature data set in the geodatabase, by the name "[county]_[water use type]_s3f."

So, for instance, Seminole County land cover data for citrus entering model step 1 (named “Seminole_citrus _s1,” in the “CFCA_SeminoleCo”.tbx toolbox) would exit as “Seminole_citrus_s1f” (or perhaps “Sem_citrus_s1f”) after it had been selected and processed
by adding area and acreage calculations, and the 60 fields that will facilitate historical acreage estimation. In model step 2, named “Seminole_citrus_s2,” the polygons are be segregated by year, and the report is exported as a .dbf file, so that it can be incorporated in the MSExcel file “Seminole_citrus_waterusedata.xlsx” to generate groundwater use estimates for each polygon. The final product of model step 2, “Seminole_citrus_s2f” (or perhaps “Sem_citrus_s2f”) forms the starting point for model step 3 in the CFCA_SeminoleCo.tbx, called “Seminole_citrus_s3.” Here, the data is joined to the MSExcel files created using data at the end of model step 2, and this is where the groundwater use estimates are linked to the polygon acreage spatial estimates. This final product, named “Seminole_citrus_s3f,” is saved in the geodatabase “Seminole_citruswateruse.gdb”.

As mentioned previously, the overall geodatabase that contains all intermediate and final data for citrus, agriculture (non-citrus), and golf courses is named “CFCA_citruswateruse.gdb.” It is unfortunate that the name contains “citrus,” but it is too difficult and time-intensive to rename it now, due to the breaking of links and so forth.

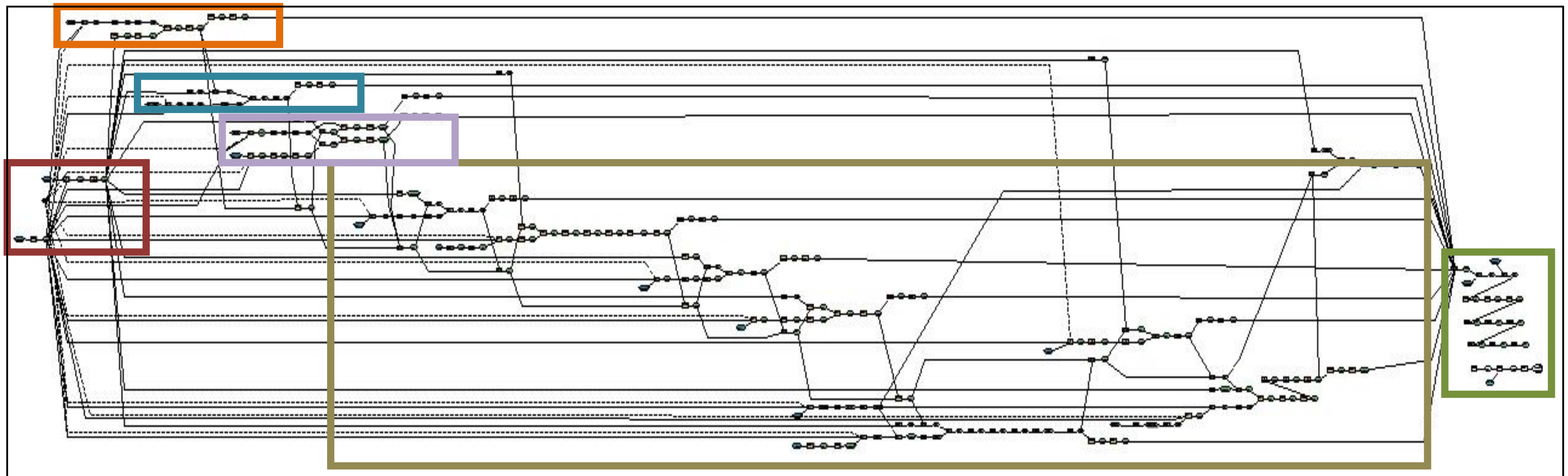
Although there are some specific differences for each county or water use type, the model steps are generally similar to each other regardless of county or water use type. So for instance, Lake_citrus_s1 is very similar to Seminole_citrus_s1 or Lake_ag_s1, and very dissimilar from Lake_citrus_s2 or Seminole_citrus_s3.

For clarification, “masks” or “mask files” represent logical improbabilities that are used to constrain other data. For instance, citrus groves cannot occupy the same location as a body of open water. “Masked out” refers to a GIS technique of erasing lands that are not appropriate in the analysis being discussed. For instance, an analysis of *land* area for a county would mask out all areas of open water because they would otherwise skew results. However, often historical citrus acreages are estimated or derived from digitized paper maps that are not as exacting as our current GIS technology. So, to compensate, once the final historical citrus grove locations are determined for a county, the water body files for that county are erased from the citrus grove locations. The citrus groves have had water bodies “masked” out. The locations were water bodies overlapped citrus groves are now erased from the data set.

MODEL STEP 1 DETAILED

Model step 1 is the most complex of the three different model steps and deals with more location specific details. See Figure C-2 for more detail. Model step 1 generally consists of the following parts:

1. **Initial Processing.** Establishment of county boundary (subunit x1-1) and selection of the appropriate public lands mask file (subunit x1-2). These files act upon all units by constraining them to the appropriate county;
2. **Unit Processing.** The processing of a unique data set (Table 1) is the basis for each unit. Each initial data set (Table 1) is clipped to the county boundary, selected for appropriate water use type, has unnecessary fields deleted (subunit y1-1), has the appropriate masks erased (subunit y1-2), intermediate mask-creating step that feeds to the next unit (subunit y1-3), and then each polygon in the unit is assigned a unique identifier number, named “FID1” (subunit y1-4) which is used much later in model step 3 to join water use estimates to the GIS file;
3. **Final Processing.** All the units are merged (subunit z1-1), have more mask files removed (such as water body coverages) (subunit z1-2), have acreages calculated (subunit z1-3), and are prepared for model step 2 via batch processing and finally saved under an intermediate file name (subunit z1-4).



Legend: **Red**= Initial Processing. **Orange**= Unit 1. **Blue**= Unit 2. **Purple**= Units 3 and 4. **Brown**= other Units. **Green**=Final Processing.

Initial processing acts independently upon all units as they are processed. The outputs from all units are merged together in final processing.

Figure C-2. Overview of model step 1

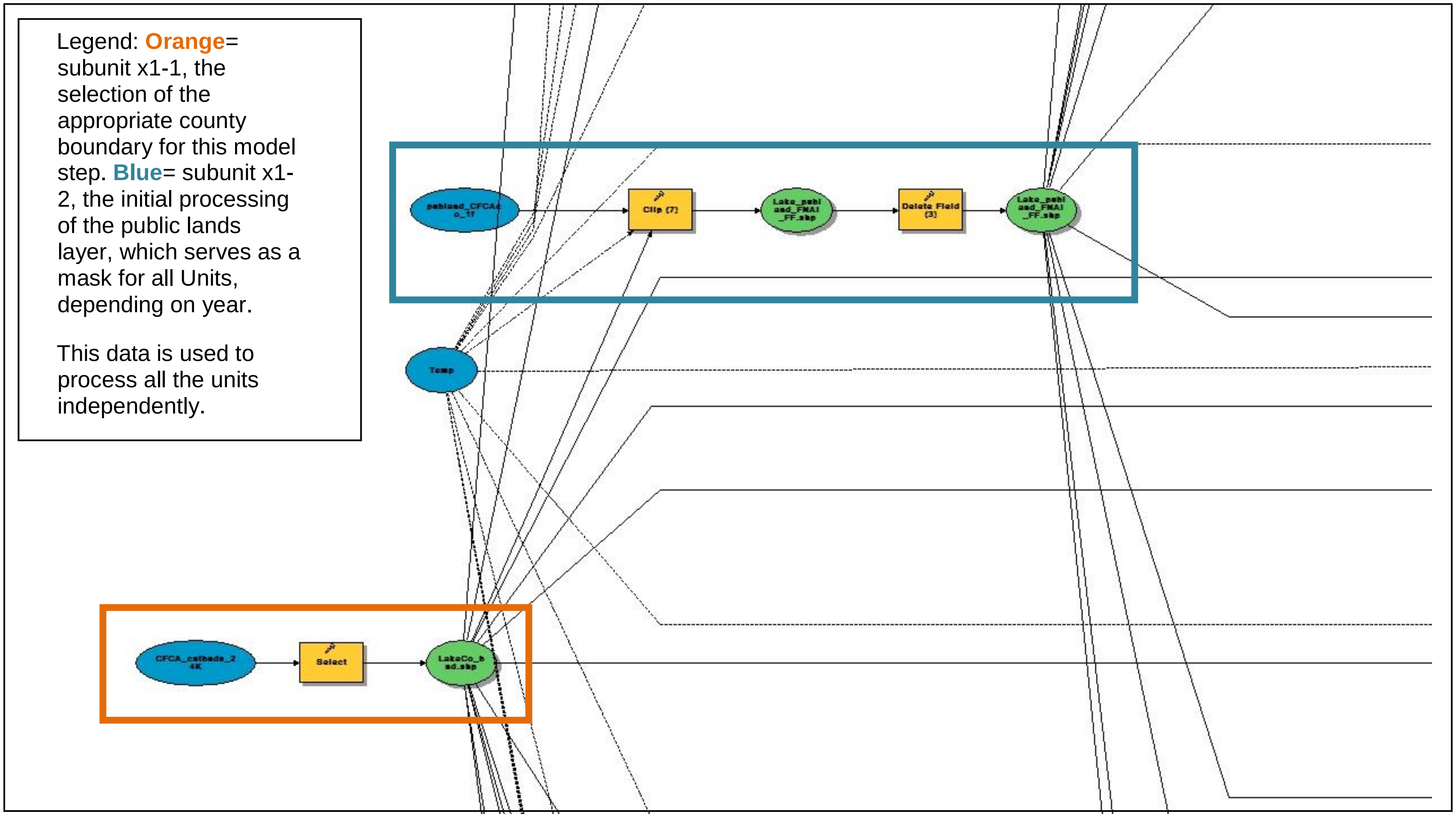
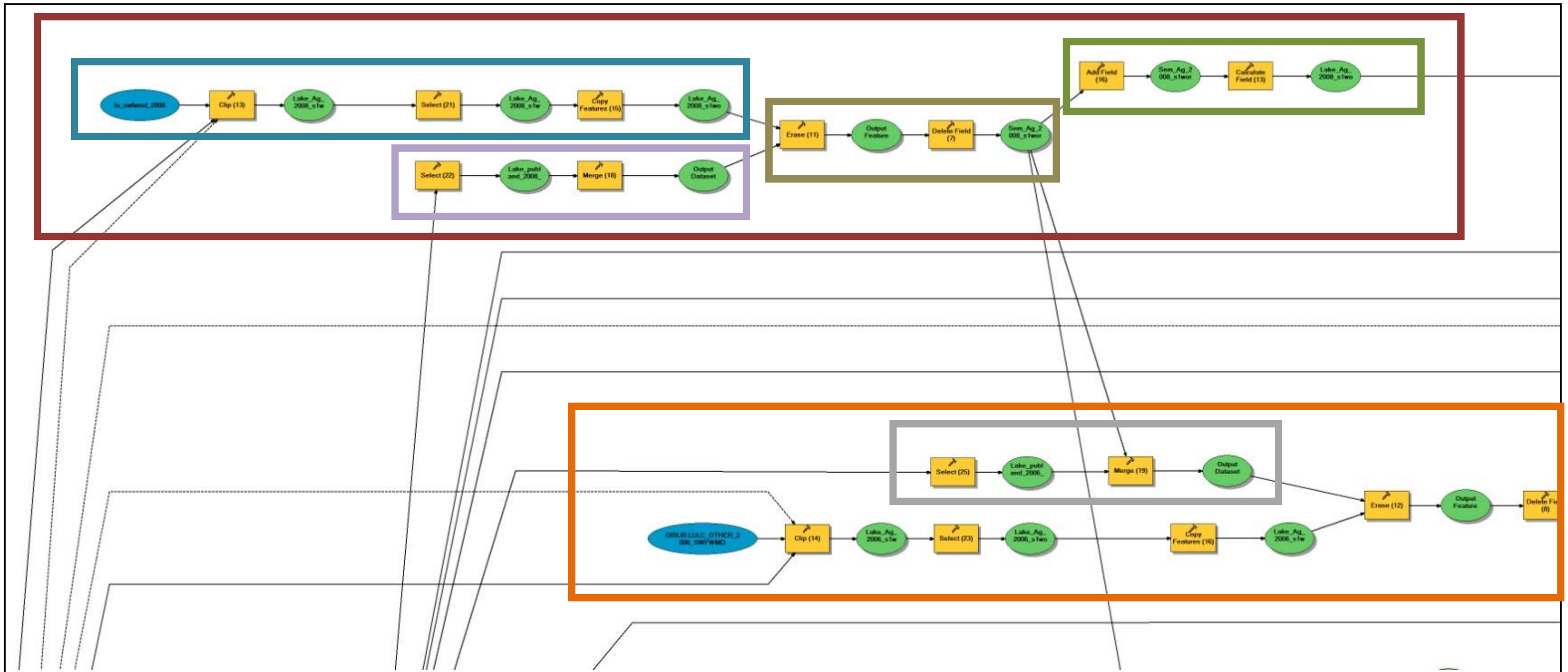


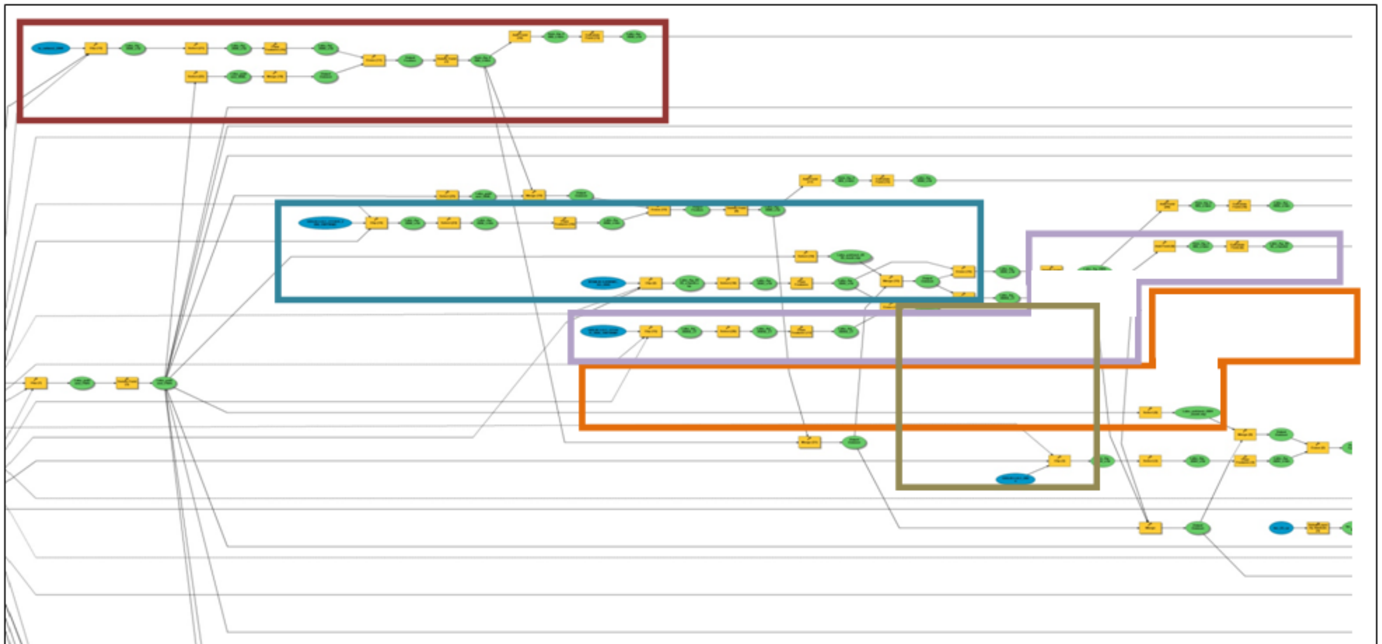
Figure C-3. Detail of model step 1, initial processing



Legend: **Red**= Unit 1. **Orange**= Unit 2 (partially shown). **Blue**= Subunit y1-1. **Purple**= Subunit y1-2. **Brown**= Subunit y1-3. **Green**= subunit y1-4. **Grey**= Subunit y2-2.

The output of subunit y1-3 feeds into subunit y1-4 and also into unit 2, subunit y2-2, which contributes to a running mask file. The output of unit 1, subunit y1-4 then proceeds to final processing where it is merged with the outputs of all other units.

Figure C-4. Detail of model step 1, example of unit processing



Legend: **Red**= Unit 1. **Blue**= Unit 2. **Purple**= Unit 3, same year data as Unit 4, but from different geographic area. **Orange**= Unit 4, same year data as Unit 3, but from different geographic area. **Brown**= Detail of a unique situation when two Units contain data from the same year that may be geographically overlapping (i.e.-for a county that spans two WMDs); the Units are processed to be mutually exclusive (i.e.-the data from one year is erased from the other).

As each Unit is processed, the data generated is then erased from the next and all subsequent Units to prevent geographic overlap that would represent a bias toward redundant data. See "Major assumptions", #10.

Figure C-5. Detail of model step 1, example of sequential unit processing

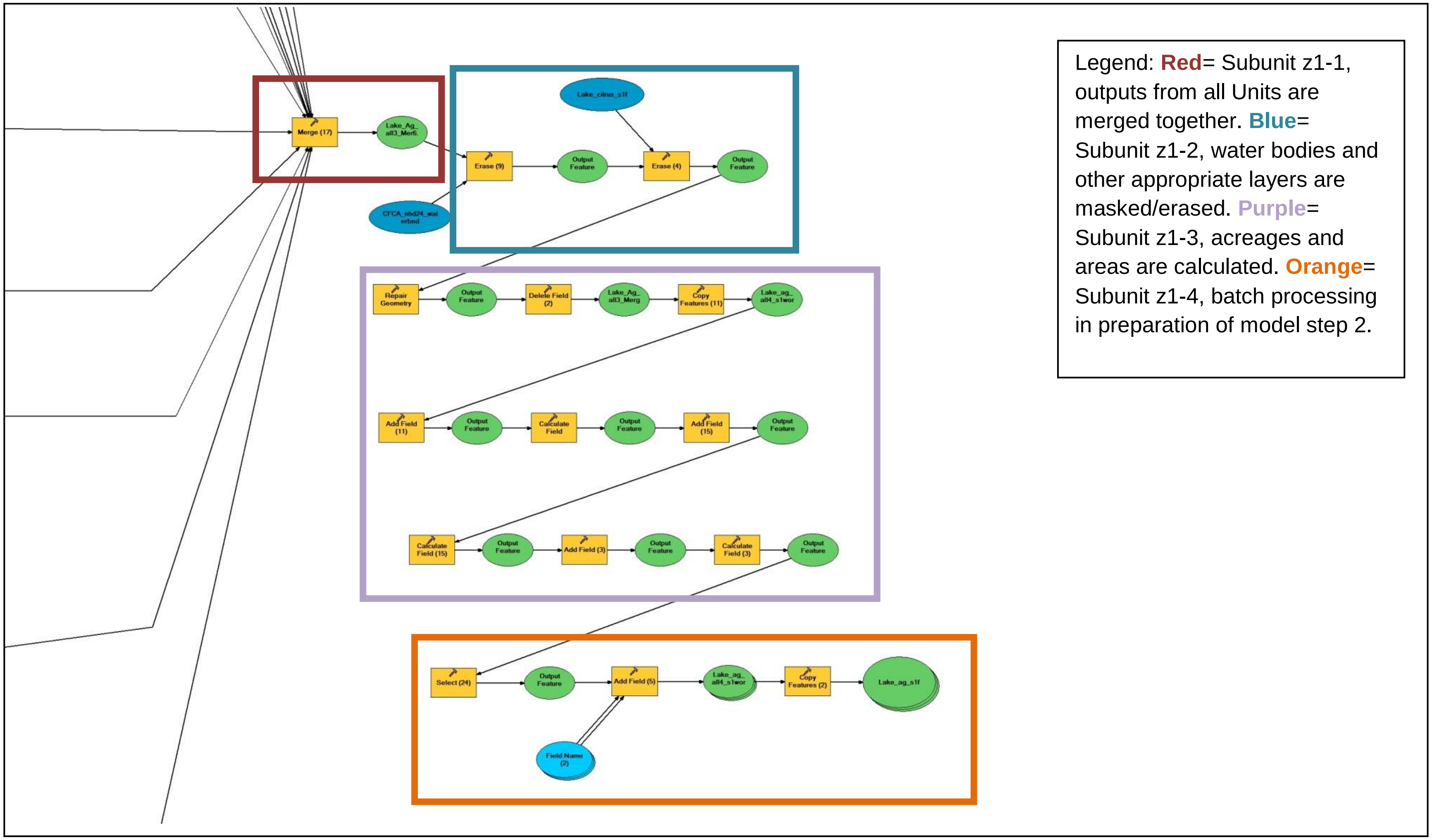
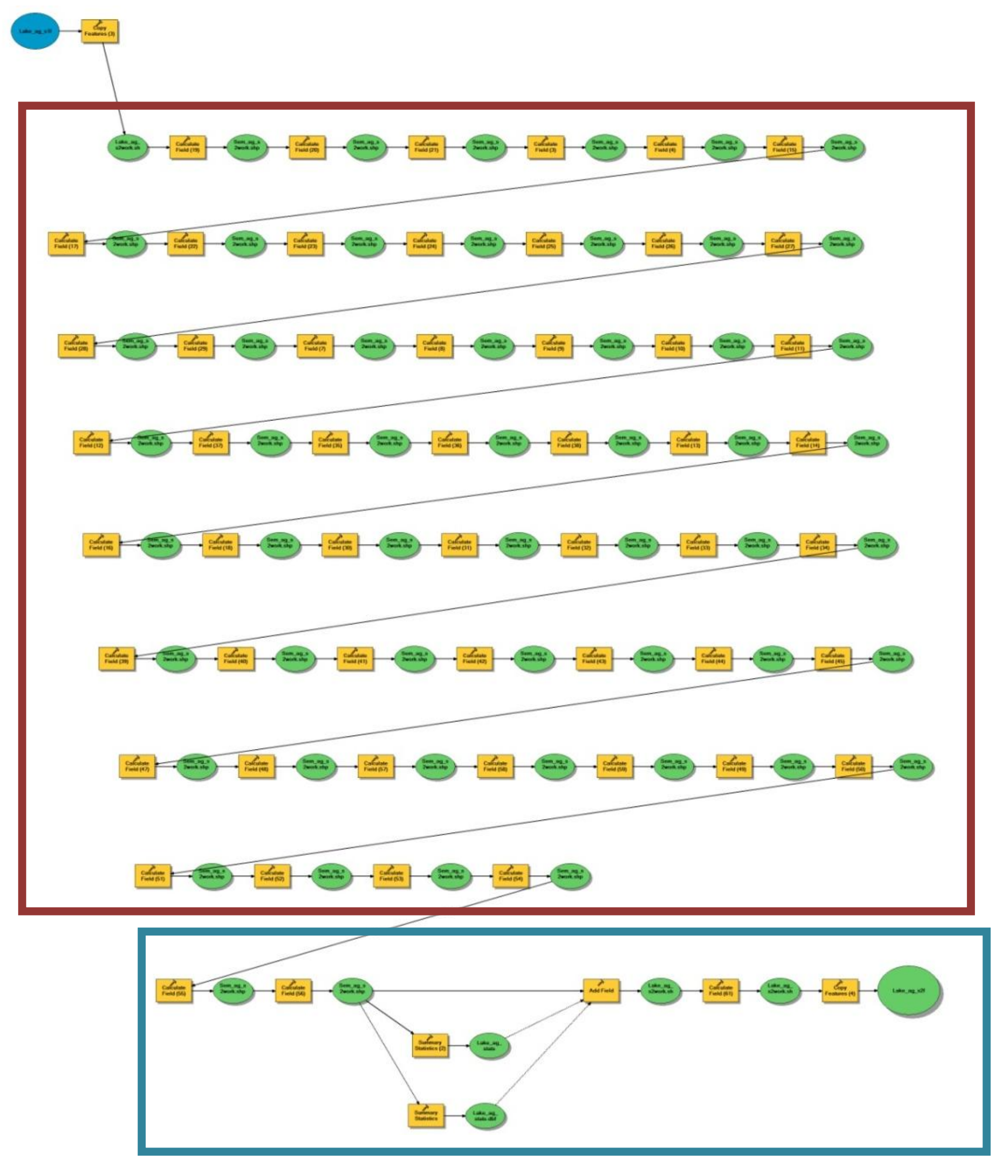


Figure C-6. Detail of model step 1, final processing

Model Step 2 Detailed

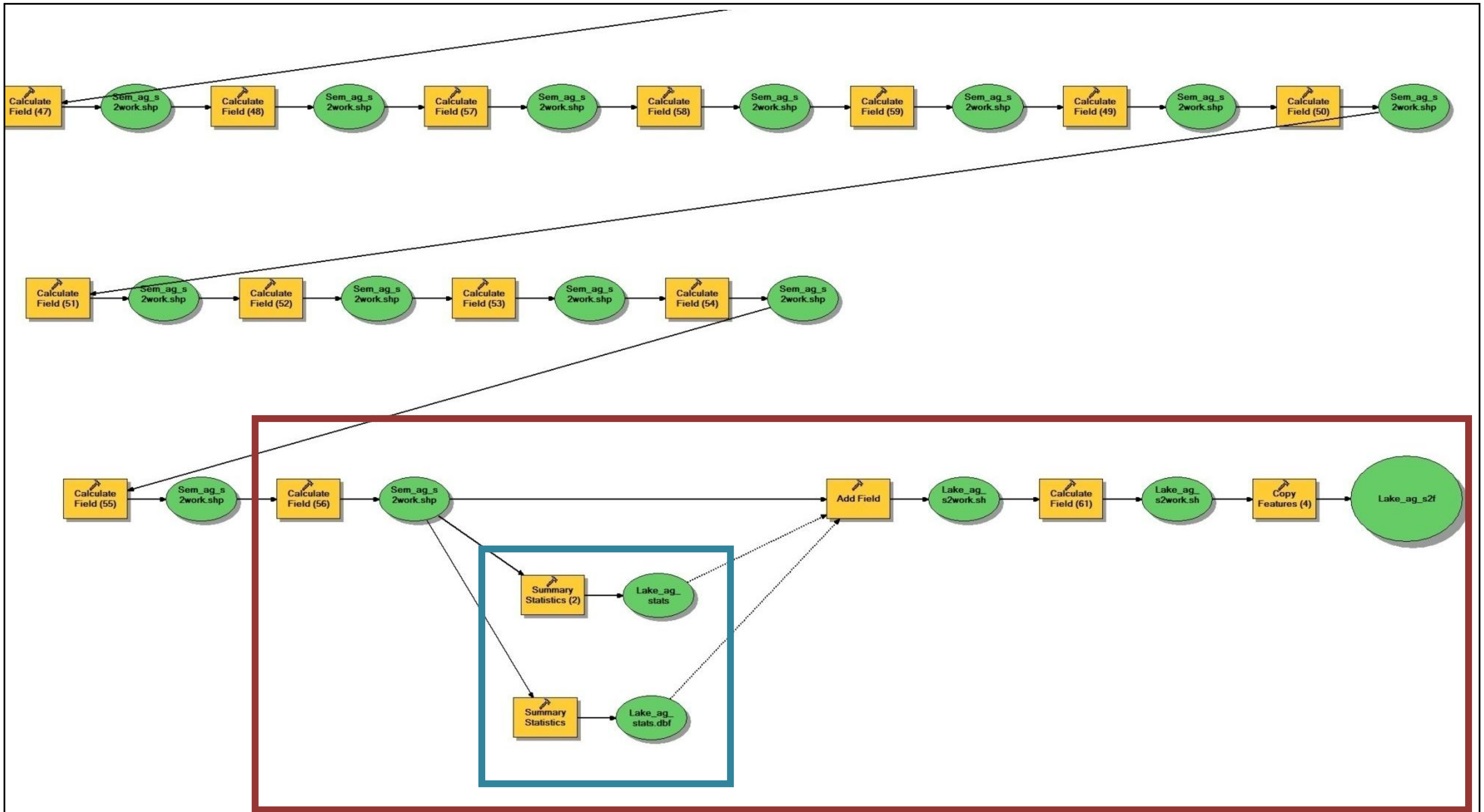
The remaining two model steps are much less complex. Model step 2 (Figures C-7, C-8) generally assigns polygons to certain years based on the data set in which they were first delineated, via their unique identifier, named “FID1” (unit 1). After this step, the Excel files used to generate the groundwater use estimates are updated using a report generated at the end of model step 2 (unit 2). The report is saved independently in the geodatabase.



Legend: **Red**= Unit 1, polygons from all years are sequentially distinguished from each other. **Blue**= Unit 2, reports are generated to help assign groundwater use estimates to each individual polygon.

The output from model step 1 enters at the top-left, is processed, and is saved at the bottom-right, which becomes the input of model step 3.

Figure C-7. Overview of model step 2



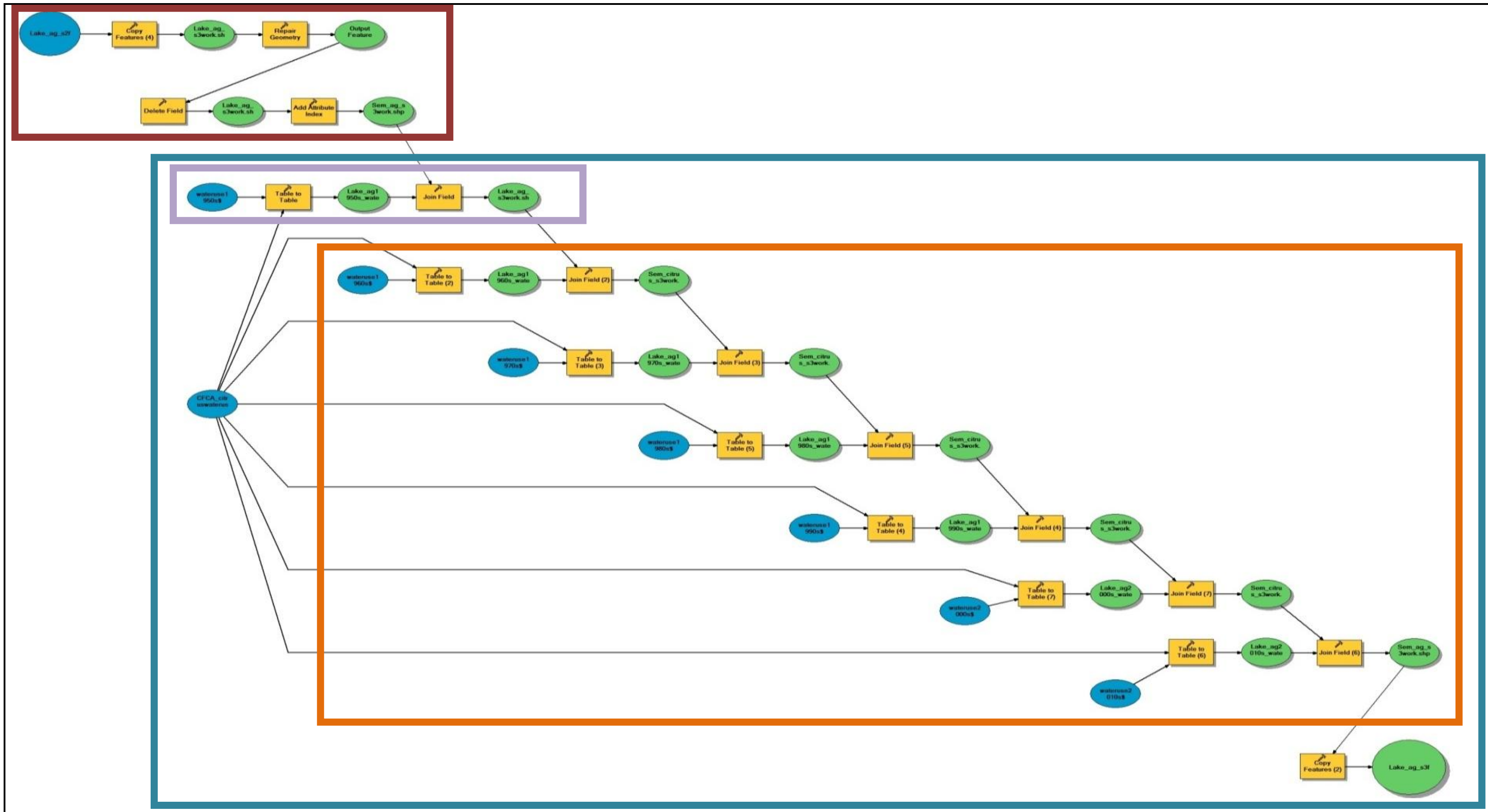
Legend: **Red**= Unit 2, in detail. **Blue**= Subunit r2-1, generates the reports of uniquely- and temporally-identified polygons that become an integral part of the Excel files (see "Excel files detailed") that are used to join the groundwater use estimates in unit 3.

Figure C-8. Detail of model step 2, unit 2

MODEL STEP 3 DETAILED

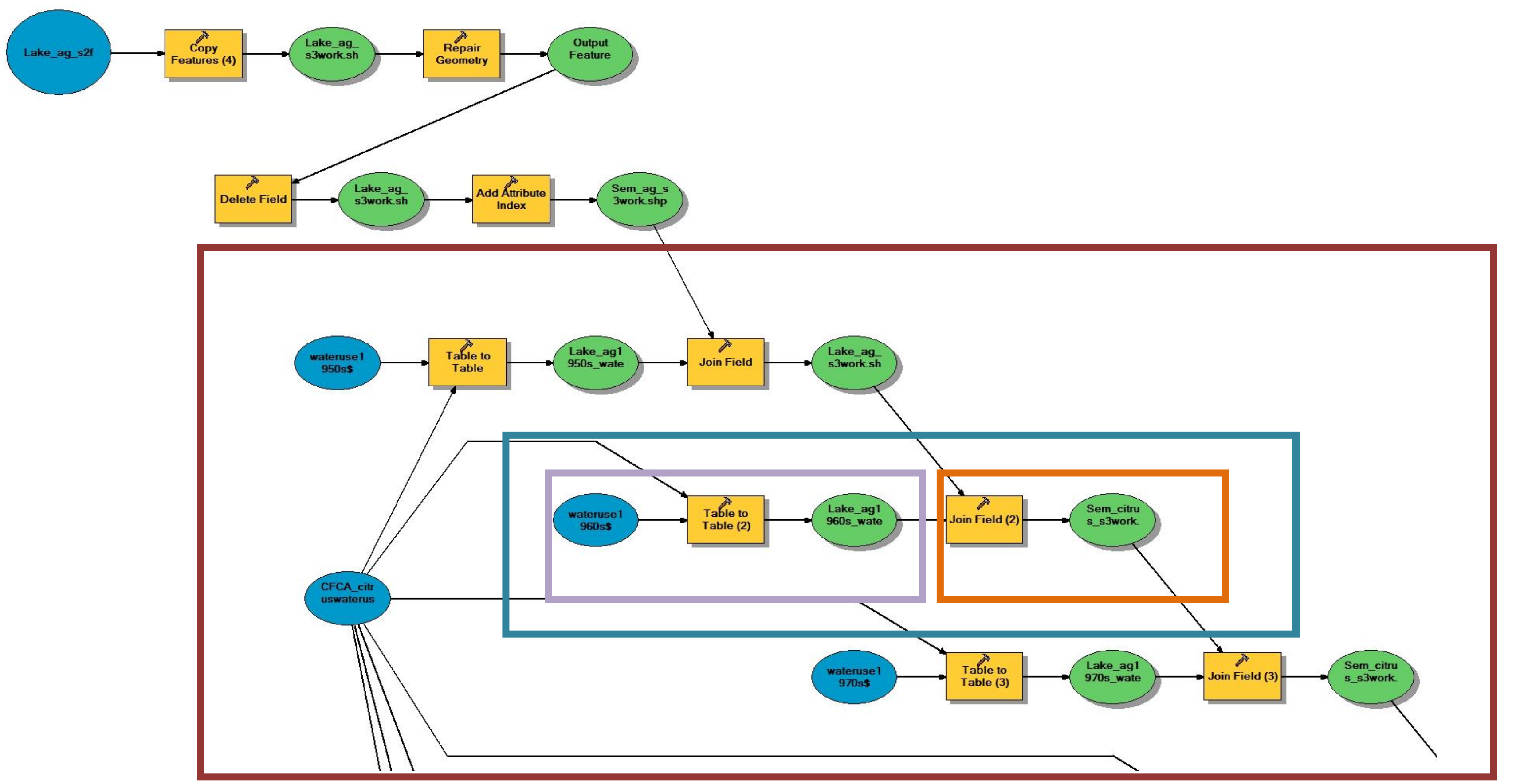
Model step 3 (Figures C-9, C-10) joins the spatial historical acreages (GIS files) that were generated in model step 1 to the historical groundwater use estimates that were generated in Excel independent of the GIS data. Preprocessing and indexing occurs in unit 1. Groundwater use tables are joined to GIS data in unit 2. The final data set is saved in the geodatabase and represents the final product of this project. Throughout all models steps, precautions are taken to attempt to minimize any conflicts that may be generated when merging complex data sets. For instance, there are several "Repair Geometry" tools that are placed to avoid overlapping polygons.

The model steps will now be dissected in an attempt to make them more transparent to the casual observer. For the sake of illustration, different counties or water use types may be displayed.



Legend: **Red**= Unit 1, simple pre-processing, geometry repair, and indexing. **Blue**= Unit 2, spatial polygon data is joined to groundwater use estimates from Excel files that utilized reports generated in model step 2, Unit 2, r2-1. **Purple**= Subunit s2-1, one decade of groundwater use estimates is joined to the spatial data. **Orange**= Other subunits. Each subunit represents a different decade of groundwater use estimates being joined to the spatial data.

Figure C-9. Overview of model step 3



Legend: **Red**= Unit 2. **Blue**= Subunit s2-2, detailed. **Purple**= The first part of subunit s2-2 retrieves the Excel file of water use data associated with this county and water use type, and converts that table to a .dbf file, which is saved in the geodatabase. **Orange**= The second part of subunit s2-2 joins the spatial data to the groundwater use estimates. This occurs sequentially to provide time-series data.

Figure C-10. Detail of model step 3, unit 2

Appendix D: Excel Files and Function

Excel Files Overview

MS Excel has been employed extensively in this project. Some Excel files have been used in the organization, estimation, creation of data linked to this project, and some Excel workbooks are used directly within the models. The folder CFCAag_wateruseworkfilesALL (Item 3, from Overview) contains the MS Excel files regarding historical groundwater use estimation are:

1. CFCA_all_wateruse_rawdata.xlsx contains the raw water use data for all the counties, and all the uses citrus, ag (non-citrus agriculture), and golf (golf courses),
2. Once those estimates and numbers were finalized, the appropriate worksheet was pasted onto the first page in the appropriate workbook called "[County name]_[water use type]_waterusedata.xlsx". So, Seminole County citrus water use data is contained in Seminole_Citrus_waterusedata.xlsx, Seminole County non-citrus agricultural data is contained in Seminole_Ag_waterusedata.xlsx, and Seminole County golf course water use data is contained in Seminole_Golf_waterusedata.xlsx. The information within these workbooks are the monthly groundwater use estimates that are later joined to the GIS files to create the final GIS product. The pages in these workbooks contain complex equations that are described in more detail later in this document.
3. CFCA_ag_use.xlsx is a relic file originally produced by Jennifer Kasper, and all of its relevant data is contained in the CFCA_all_wateruse_rawdata.xlsx file (mentioned above). It remains mostly unused, and is redundant, but retained just in case.
4. Excel files CitrusWaterUse_AnnualDistr, AgWaterUse_AnnualDistr.xlsx, and GolfWaterUse_AnnualDistr.xlsx contain the data that was used to generate the water use allocation numbers that are contained in the second page of the workbook (Item 2, from Overview). The data is monthly proportional distribution of water use for each "crop" type. It is based on best estimates, and some available historical data.
5. Files like Copy of Historical AG-REC Water Use 1978-2009_BruceFlorence.xlsx, FASSData_SWFWMD.xlsx (which is identical to DistrictFASSData.xls, contained in subfolder SWFWMDdata), Water source data comparison 101410.xlsx, and SeminoleCo_data problems 100610.xlsx, are either used for further information gathering (like the first two files mentioned) or for initially describing problems in gathering and identifying accurate sources of data (like the last two files mentioned).
6. Other files in this folder (MSWord, .pdf, etc.) often provide relevant information to the process or background information.

Excel Files Detailed

Within the folder CFCAag_wateruseworkfilesALL, there is an MSExcel workbook for each combination of County (Lake, Orange, Osceola, Polk, and Seminole) and land cover (citrus, ag (non-citrus agriculture), and golf course). They are named by "[county]_[land cover]_waterusedata.xlsx," so that golf course data from Lake County is stored in the MSExcel workbook named "Lake_Golf_waterusedata.xlsx". These Excel workbooks contain the formulas and raw data that calculate the groundwater use estimates, which are ultimately joined to the GIS polygon data to create the final GIS product. These workbooks are referenced explicitly within model step 3 for each county and each water use type. The following worksheets, within each workbook are common to all land cover data sets:

1. **rawdata**: This worksheet contains data copy-and-pasted from the workbook CFCA_all_wateruse_rawdata.xlsx, which represents the best estimates of groundwater use by year for each county. After the data is pasted-in, the workbook is manipulated to utilize the appropriate land cover type (citrus, ag, or golf), and these best estimates of groundwater use referenced to Column B of page "workdatayrs," labeled "gwuse_GPD".
2. **workdatayrs**: This worksheet contains groundwater use estimates from the rawdata worksheet, monthly irrigation requirement estimates as obtained from the appropriate annual water use distribution workbook (files CitrusWaterUse_AnnualDistr, AgWaterUse_AnnualDistr.xlsx, or GolfWaterUse_AnnualDistr.xlsx), and polygon acreage data from the statistical summary in model step 2 of the appropriate model. The polygon acreage data (fields labeled "fid1" and "p[year]") was copied-and-pasted from the .dbf file created from the statistical summary at the end of model step 2 of the appropriate model (see Item 2 in Models Overview). This data is then used to calculate fields labeled "pct[year]," which represent each polygons proportional area of all the polygons present in that year.
    a. For instance, the worksheet "workdatayrs" in Lake_Golf_waterusedata.xlsx would contain:
        i. the year in Column A, labeled "year"
        ii. annual golf course groundwater use estimates in Column B ("gwuse_GPD," which are copied from the appropriate column in the rawdata worksheet (which was itself copied from CFCA_all_wateruse_rawdata.xlsx), in units of average gallons of groundwater per day by year; this is equivalent to the gwuse from the raw data worksheet multiplied by 1,000,000 (to convert to gallons) and then multiplied by 365 (days per year);
        iii. monthly proportional irrigation requirements (for golf courses, or turf) in Columns D through O (as generated from the appropriate xxx_WaterUse_AnnualDistr.xlsx workbook); the appropriate coefficient of monthly distribution is divided by the number of days in that month; when combined with the multiplication by days in the previous column, the end units become "average gallons per day by month";
        iv. the "fid1" field (Column P), which is equivalent to both "FID1" (from the ArcToolbox models), and "polyid" (from subsequent worksheets within this workbook);
        v. polygon acreage data for each year (obtained from Lake_golf_s2, which is located in the CFCA_LakeCo.tbx toolbox) in Columns Q through BR;

vi. corresponding calculated proportional acreage for each year (in Columns BS through DT).

3. **wateruse1950s** through **wateruse2010s**: This data is presented in average gallons of groundwater per day, by month, for years 1957 through 2010, for each polygon in the data set. It is tracked by the field "polyid" (which is equivalent to "FID1" or "fid1"), and is used to join this data to the spatial GIS polygon data in model step 3 of the appropriate model (see Item 3 in Model Overview, Appendix C). Each unique polygon's groundwater use estimate is calculated by multiplying that year's annual groundwater use (worksheet "workdatayrs," Column B) times the appropriate month's proportional irrigation requirement (worksheet "workdatayrs," Columns D through O) times the appropriate proportional acreage for that polygon (worksheet "workdatayrs," Columns BS through DT). In this way, groundwater use is estimated proportionately based on the month of the year and a polygon's size. This provides a coarse groundwater use estimate that assumes a large amount of similarity in management and resource access between all polygons.

Other Excel workbooks are used in a support capacity. For instance, there are three workbooks that detail monthly distribution of water for each water use type. See Chapter 6 for more detail.

APPENDIX E: HISTORICAL ACREAGE DELINEATION SELECTION CRITERIA

Tables E1 through E-5 describe the exact criteria used to establish historical acreages based on the available data sources. Several water management districts spanned most counties. NASS data was only available for the St. Johns River Water Management District portion of the study area.

Table E-1. Base GIS data used in delineation of historical acreages in Lake County

GIS base layer	Relevant Year	Agriculture (non-citrus)	Citrus	Golf	Notes
NASSactive_10	2010		J		Citrus only
NASSinactive_10	2009-2005		J		Citrus only
lu_swfwmd_2008	2008	W	W*	W*	Before model step 3: copy ag to 2010.
GISLIB.LULC_OTHER_2006_SWFWMD	2006	W	W*	W	
WSMLIB.SJRWMD_AG_2005	2005	J	J		Before model step 3: copy ag to 2010.
GISLIB.LULC_OTHER_2005_SWFWMD		W	W	W*	
GISLIB.LULC_OTHER_2004_SFWMD	2004				Before model step 3: copy ag and Citrus to 2010.
GISLIB.LULC_2004		J	J	J	
fwc_03_sjr	2003	J	J		Converted from raster data, constrained by usgslu_1974.
lake1999_lu0035	1999	C	C	C	
GISLIB.LULC_1995 –sjr	1995	J	J	J	
GISLIB.LULC_OTHER_1995_SWFWMD		W*	W		
GISLIB.LULC_OTHER_1995_SFWMD					
lake_1993_gap_lcov35	1993	C	C		Converted from raster data, constrained by usgslu_1974.
lake1990_lu9035	1990	C	C	C	Before model step 3: copy Golf back to 1980
Land Cover 1985-1989 FWC raster	1985	C	C		Converted from raster data, constrained by usgslu_1974.
usgslu_1974	1974	C	C		also used to constrain raster data from 1993 and 1985.

LEGEND:
C = complete area covered, data set covers the entire county
F = partial area covered, only the SFWMD side of the county
J = partial area covered, only the SJRWMD side of the county
W = partial area covered, only the SWFWMD side of the county
* = area is covered, but it's redundant or no polygons are present.

Table E-2. Base GIS data used in delineation of historical acreages in Orange County

	Relevant Year	Agriculture (non-citrus)	Citrus	Golf	Notes
NASSactive_10	2010		J		Citrus only
NASSinactive_10	2009-2005		J		Citrus only
lu_swfwmd_2008	2008				
GISLIB.LULC_OTHER_2006_SWFWMD	2006				
WSMLIB.SJRWMD_AG_2005	2005	J	J		Before model step 3: copy ag to 2010.
GISLIB.LULC_OTHER_2005_SWFWMD					
GISLIB.LULC_OTHER_2004_SFWMD	2004	F	F	F	Before model step 3: copy ag and Citrus to 2010.
GISLIB.LULC_2004		J	J	J	
fwc_03_sjr	2003	J	J		Converted from raster data, constrained by usgslu_1974.
orange1999_lu0048	1999	C	C	C	
GISLIB.LULC_1995 -sjr	1995	J	J	J	
GISLIB.LULC_OTHER_1995_SWFWMD					
GISLIB.LULC_OTHER_1995_SFWMD		F	F	F	
orange_1993_gap_lcov48	1993	C	C		Converted from raster data, constrained by usgslu_1974.
orange1990_lu9048	1990	C	C	C	Before model step 3: copy Golf back to 1978
Land Cover 1985-1989 FWC raster	1985	C	C		Converted from raster data, constrained by usgslu_1974.
usgslu_1974	1974	C	C		also used to constrain raster data from 1993 and 1985.

LEGEND:
C = complete area covered, data set covers the entire county
F = partial area covered, only the SFWMD side of the county

J = partial area covered, only the SJRWMD side of the county
W = partial area covered, only the SWFWMD side of the county
* = area is covered, but it's redundant or no polygons are present.

Table E-3. Base GIS data used in delineation of historical acreages in Osceola County

GIS base layer	Relevant Year	Agriculture (non-citrus)	Citrus	Golf	Notes
NASSactive_10	2010		J		Citrus only
NASSinactive_10	2009-2005		J		Citrus only
lu_swfwmd_2008	2008				
GISLIB.LULC_OTHER_2006_SWFWMD	2006				
WSMLIB.SJRWMD_AG_2005	2005	J	J		Before model step 3: copy ag to 2010
GISLIB.LULC_OTHER_2005_SWFWMD					
GISLIB.LULC_OTHER_2004_SFWMD	2004	F	F	F	Before model step 3: copy ag and Citrus to 2010
GISLIB.LULC_2004		J	J	J	
fwc_03_sjr	2003	J	J		Converted from raster data, constrained by usgslu_1974
osceola1999_lu0049	1999	C	C	C	
GISLIB.LULC_1995 -sjr	1995	J	J	J*	
GISLIB.LULC_OTHER_1995_SWFWMD					
GISLIB.LULC_OTHER_1995_SFWMD		F	F	F	
osceola_1993_gap_lcov49	1993	C	C		Converted from raster data, constrained by usgslu_1974.
osceola1990_lu9049	1990	C	C	C	Before model step 3: copy Golf back to 1980
Land Cover 1985-1989 FWC raster	1985	C	C		Converted from raster data, constrained by usgslu_1974.
usgslu_1974	1974	C	C		also used to constrain raster data from 1993 and 1985.

LEGEND:
C = complete area covered, data set covers the entire county
F = partial area covered, only the SFWMD side of the county
J = partial area covered, only the SJRWMD side of the county

W = partial area covered, only the SWFWMD side of the county
* = area is covered, but it's redundant or no polygons are present.

Table E-4. Base GIS data used in delineation of historical acreages in Polk County

GIS base layer	Relevant Year	Agriculture (non-citrus)	Citrus	Golf	Notes
NASSactive_10	2010				Citrus only; Does not cover Polk County
NASSinactive_10	2009-2005				Citrus only; Does not cover Polk County
lu_swfwmd_2008	2008	W	W	W	Before model step 3: copy ag and Citrus to 2010
GISLIB.LULC_OTHER_2006_SWFWMD	2006	W	W	W	
WSMLIB.SJRWMD_AG_2005	2005				
GISLIB.LULC_OTHER_2005_SWFWMD		W	W	W	
GISLIB.LULC_OTHER_2004_SFWMD	2004	F	F	F	Before model step 3: copy ag and Citrus to 2010
GISLIB.LULC_2004		J	J	J	Before model step 3: copy ag and Citrus to 2010
fwc_03_sjr	2003				Does not cover Polk County
polk1999_lu0053	1999	C	C	C	
GISLIB.LULC_1995 -sjr	1995	J	J	J	
GISLIB.LULC_OTHER_1995_SWFWMD		W	W		
GISLIB.LULC_OTHER_1995_SFWMD		F	F	F	
polk_1993_gap_lcov53	1993	C	C		Converted from raster data, constrained by usgslu_1974
polk1990_lu9053	1990	C	C	C	Before model step 3: copy Golf back to 1977
Land Cover 1985-1989 FWC raster	1985	C	C		Converted from raster data, constrained by usgslu_1974
usgslu_1974	1974	C	C		Also used to constrain raster data from 1993 and 1985

LEGEND:
C = complete area covered, data set covers the entire county
F = partial area covered, only the SFWMD side of the county
J = partial area covered, only the SJRWMD side of the county
W = partial area covered, only the SWFWMD side of the county
* = area is covered, but it's redundant or no polygons are present.

Table E-5. Base GIS data used in delineation of historical acreages in Seminole County

GIS base layer	Relevant Year	Agriculture (non-citrus)	Citrus	Golf	Notes
NASSactive_10	2010		C		Citrus only
NASSinactive_10	2009-2005		C		Citrus only
lu_swfwmd_2008	2008				
GISLIB.LULC_OTHER_2006_SWFWMD	2006				
WSMLIB.SJRWMD_AG_2005	2005	C	C		
GISLIB.LULC_OTHER_2005_SWFWMD					
GISLIB.LULC_OTHER_2004_SFWMD	2004				
GISLIB.LULC_2004		C	C	C	
fwc_03_sjr	2003	C	C		Converted from raster data, constrained by usgslu_1974.
seminole1999_lu0059	1999	C	C	C	
GISLIB.LULC_1995 -sjr	1995	C	C	C	
GISLIB.LULC_OTHER_1995_SWFWMD					
GISLIB.LULC_OTHER_1995_SFWMD					
seminole_1993_gap_lcov59	1993	C	C		Converted from raster data, constrained by usgslu_1974.
seminole1990_lu9059	1990	C	C	C	Before model step 3: copy Golf back to 1980.
Land Cover 1985-1989 FWC raster	1985	C	C		Converted from raster data, constrained by usgslu_1974.
usgslu_1974	1974	C	C		also used to constrain raster data from 1993 and 1985.

LEGEND:
C = complete area covered, data set covers the entire county
F = partial area covered, only the SFWMD side of the county
J = partial area covered, only the SJRWMD side of the county
W = partial area covered, only the SWFWMD side of the county

* = area is covered, but it's redundant or no polygons are present.

Appendix F: Agriculture (Non-Citrus) Groundwater Use Estimation Data Accuracy

Table F-1 shows the relative accuracy of groundwater use estimates for each time period in this project. This is a qualitative table that ranks the accuracy of each time period in each county relative to itself, as well as relative to other counties. Rankings can be assumed to be comparable across counties. However, asterisked rankings should be used to compare between counties when present.

Table F-1. Relative accuracy of agricultural (non-citrus) groundwater use estimations

Lake County: Groundwater use estimation accuracy for agriculture (non-citrus)		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1977	c	linear extrapolation based on ratio of estimated citrus groundwater to total ag groundwater, in SJRWMD normalized to county
1977–1978, 1987–1989	b (*a)	average of two methods: #1- SJRWMD total ag, normalized to county, and #2- estimate produced by USGS for whole county
1979–1981, 1985, 1990, 1995	a	SWFWMD, USGS, and SJRWMD whole county estimates
1982–1984, 1986, 1991–1994, 1996–2000, 2005	b (*a)	average of three methods: #1- SJRWMD total ag, normalized to county, #2- estimate produced by USGS for whole county, and #3- sum of WMD estimates (SJRWMD and SWFWMD)
2002–2004, 2006–2010	b (*a)	average of two methods: #1- SJRWMD total ag, normalized to county, and #3- sum of WMD estimates (SJRWMD and SWFWMD)
Orange County: Groundwater use estimation accuracy for agriculture (non–citrus)		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1962, 1964, 1966–1968, 1971–1973, 1976	c	method #1- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times whole county estimated citrus groundwater use
1963	c	average of two methods: #1- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times whole county estimated citrus groundwater use, and #2- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times average of two USGS whole county citrus groundwater use estimates

1965, 1969–1970, 1974–1975, 1977	b (*a)	average of three methods: #1- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times whole county estimated citrus groundwater use, #2- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times average of two USGS whole county citrus groundwater use estimates, and #3- USGS reported or linearly interpolated total ag groundwater use estimates
1978–1979, 1981–1984, 1986–1989, 1991–1994, 1996–1999, 2001–2004, 2006–2010	a	average of three methods: #1- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times whole county estimated citrus groundwater use, #2- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times average of two USGS whole county citrus groundwater use estimates, and #4- SJRWMD ag normalized to whole county
1980, 1985, 1990, 1995, 2000, 2005	a	average of four methods: #1- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times whole county estimated citrus groundwater use, #2- linear extrapolation based on SJRWMD ratio of citrus groundwater use to total ag groundwater use times average of two USGS whole county citrus groundwater use estimates, #3- USGS reported or linearly interpolated total ag groundwater use estimates, and #4- SJRWMD ag normalized to whole county

Osceola County: Groundwater use estimation accuracy for agriculture (non–citrus)

Time period	Data Accuracy	Method/Comment
1950–1956	n/a	not estimated
1957–2010	a (*b)	linearly extrapolated and interpolated from estimated whole county citrus groundwater use, based on a ratio of USGS reported citrus groundwater use to ag groundwater use; very little data was gathered from SFWMD; this data is highly estimated; although this data may appear somewhat inaccurately estimates, the trends estimated are approximated by other, less accurate estimation techniques, lending validity to the results

Polk County: Groundwater use estimation accuracy for agriculture (non–citrus)

Time period	Data Accuracy	Method/Comment
1950–1956	n/a	not estimated
1957–1958, 1960–1963, 1966–1968, 1970–1973	d	method #1- whole county citrus groundwater use estimate linearly extrapolated and interpolated from running average of five years (or overall average if data not available) of the ratio of the average of several different citrus groundwater estimation methods to the average of several different ag groundwater estimation methods
1959, 1964–1965, 1969, 1974–1978	c	average of two methods: #1- whole county citrus groundwater use estimate linearly extrapolated and interpolated from running average of five years (or overall average if data not available) of the ratio of the average of several different citrus groundwater estimation methods to the average of several different ag groundwater estimation methods, and #2- USGS reported or ratio-interpolated data
1979–1981	b	average of two methods: #2- USGS reported or ratio-interpolated data, and #3- SWFWMD whole county estimated data, or partial county data normalized to whole county

1982–1984, 1986–1989, 1991–1994, 1996–1997	a	average of two methods: #3- SWFWMD whole county estimated data, or partial county data normalized to whole county, and #4- sum of WMD reported data (SWFWMD, and SJRWMD), normalized to whole county to accommodate missing SFWMD data; only SWFWMD data used from 2003-2010 due to change in WMD boundaries
1985, 1990, 1995	a	average of three methods: #2- USGS reported or ratio-interpolated data, #3- SWFWMD whole county estimated data, or partial county data normalized to whole county, and #4- sum of WMD reported data (SWFWMD, and SJRWMD), normalized to whole county to accommodate missing SFWMD data; only SWFWMD data used from 2003-2010 due to change in WMD boundaries
1998–2010	a	method #4- sum of WMD reported data (SWFWMD, and SJRWMD), normalized to whole county to accommodate missing SFWMD data; only SWFWMD data used from 2003-2010 due to change in WMD boundaries

Seminole County: Groundwater use estimation accuracy for agriculture (non–citrus)		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1977	c	method #1- linear extrapolation from estimated citrus groundwater use based on ratio of SJRWMD reported citrus groundwater use to reported ag groundwater use
1978–2000	a	SJRWMD reported data; SJRWMD encompasses the entire county
2001–2010	b (*a)	linear extrapolation and interpolation from estimated citrus groundwater use based on ratio of SJRWMD reported citrus groundwater use to reported ag groundwater use, with more reported data available than the 1957–1977 data
a = most accurate/most reliable/less data filling, d = less accurate/less reliable/more data filling		
*relative to this county only, this data is accurate based on the first rating; relative to other counties' ag data, it is more similar to the asterisked accuracy rating.		

APPENDIX G: CITRUS GROUNDWATER USE ESTIMATION DATA ACCURACY

Table G-1 highlights the impact that citrus had in 1995 on groundwater consumption, long after the major freezes pushed citrus farming further south. It demonstrates the impact that citrus groves have on groundwater withdrawals in the CFCA. It also justifies the assumption that 90% of total citrus water use came from groundwater, which was occasionally used to estimate citrus groundwater use when other data were lacking.

Table G-1. Comparison of groundwater use estimates for CFCA

Agriculture for year 1995					
County	**Crop**	**%Groundwater**	**% Surface water**	**Citrus total water use (est. mgd)**	**Citrus groundwater use (est. mgd)**
Lake	citrus	87%	13%	>29.51	>25.67
Polk	citrus	90%	10%	>3.0	>2.0
Orange	citrus	90%	10%	>6.0	>5.09
Osceola	citrus	100%	0%	>6.0	>6.0
Seminole	citrus	100%	0%	3.01	3.01
Source: AGRY95.XLS					

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Table G-2 shows the relative accuracy of groundwater use estimates for each time period in this project. This is a qualitative table that ranks the accuracy of each time period in each county relative to itself, as well as relative to other counties. Rankings can be assumed to be comparable across counties. However, asterisked rankings should be used to compare between counties when present. So, for instance, the groundwater use estimates generated for Lake County during 2000, although a less accurate estimate than data in Lake County for 2001–2010, is still comparable to the best estimations from other counties.

Table G-2. Relative accuracy of citrus groundwater use estimations and methods

Lake County: Groundwater use estimation accuracy for citrus		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1977	c	exponential extrapolation, normalized to the county of the ratio of estimated citrus groundwater use to FASS citrus tree count; curve based on best estimated citrus groundwater use data from 1978-2000 (data from WMDs, USGS, and FASS)
1978–1982, 1987–1989	b	SJRWMD AWS normalized to county
1983–1984, 1986	b	sum of WMD estimates
1985	a	USGS whole county estimate
1990, 1995, 1998–1999	b (*a)	average of USGS whole county estimate and sum of WMD estimates
1991–1994, 1996–1997	a	sum of WMD estimates
2000	b (*a)	sum of WMD estimates, includes average of adjacent years in SWFWMD estimate
2001–2010	a	sum of extrapolated WMD estimates
Orange County: Groundwater use estimation accuracy for citrus		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1962, 1964, 1966–1968, 1971–1973, 1976	c	data filling using a running average based on an average of two estimation methods using USGS data, as a ratio to the FASS citrus tree count.
1963,1965, 1969–1970, 1974–1975, 1977	c	average of two methods: #1- an average of two estimation methods using USGS data, and #2- data filling using a running average based on the previously described average (see #1) as a ratio to the FASS citrus tree count.
1978–1979, 1981–1984, 1986–1989, 1991–1994, 1996–1999, 2001–2004, 2006–2010	b (*a)	an average of three methods: #2- data filling using a running average based on the average of two USGS estimates (see #1) as a ratio to the FASS citrus tree count, #3- SJRWMD estimates normalized to the county, and #4- the sum of WMD estimates.
1980, 2000, 2005	b (*a)	an average of four methods: #1- an average of two estimation methods using USGS data, #2- data filling using a running average based on the previously described average (see 1.) as a ratio to the FASS citrus tree count, #3- SJRWMD estimates normalized to the county, and #4- the sum of WMD estimates.
1985, 1990, 1995	a	USGS whole county estimate from recent years
Osceola County: Groundwater use estimation accuracy for citrus		
Time period	**Data**	**Method/Comment**

	Accuracy	
1950–1956	n/a	not estimated
1957–1964, 1966–1969, 1971–1973, 1976	c	average of two methods: #1- exponential extrapolation of the average curve generated from three separate methods that use the ratio of estimated citrus groundwater use from different sources to FASS citrus tree count; curve based on best estimated citrus groundwater use data from 1965-2010 (data from WMDs, USGS, and FASS), and #2- a linear extrapolation based on the ratio of known USGS whole county citrus groundwater estimates to FASS citrus tree count
1965, 1970, 1974–1975, 1977	c	average of three methods: #1- exponential extrapolation of the average curve generated from three separate methods that use the ratio of estimated citrus groundwater use from different sources to FASS citrus tree count; curve based on best estimated citrus groundwater use data from 1965-2010 (data from WMDs, USGS, and FASS), #2- a linear extrapolation based on the ratio of known USGS whole county citrus groundwater estimates to FASS citrus tree count, and #3- an average of two USGS estimates
1978–1979	b	average of two methods: #2- a linear extrapolation based on the ratio of known USGS whole county citrus groundwater estimates to FASS citrus tree count, and #4- SJRWMD citrus groundwater use normalized to the whole county
1980, 2000, 2005	b	average of four methods: #2- a linear extrapolation based on the ratio of known USGS whole county citrus groundwater estimates to FASS citrus tree count, #3- an average of two USGS estimates, #4- SJRWMD citrus groundwater use normalized to the whole county, and #5- sum of WMD estimates from SJRWMD and SFWMD
1981–1984, 1986–1989, 1991–1994, 1996–1999, 2001–2004, 2006–2010	b	average of three methods: #2- a linear extrapolation based on the ratio of known USGS whole county citrus groundwater estimates to FASS citrus tree count, #4- SJRWMD citrus groundwater use normalized to the whole county, and #5- sum of WMD estimates from SJRWMD and SFWMD
1985, 1990, 1995	a	USGS whole county estimate from recent years

Polk County: Groundwater use estimation accuracy for citrus		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1958, 1960–1961	d	#1- assumed that 90% of total water use by citrus was groundwater, linearly interpolating from SWFWMD groundwater use estimates with nearest data points at 1956 and 1962
1962–1963, 1966–1968, 1970–1973	c	#1- assumed that 90% of total water use by citrus was groundwater, using a SWFWMD groundwater use estimates with data points at every other year
1959, 1964–1965, 1969, 1974–1978	c	average of two methods: #1- assumed that 90% of total water use by citrus was groundwater, using a SWFWMD groundwater use estimates with data points at every other year, and #2- estimates generated from linear and ratio interpolation and extrapolation of USGS data via various methods
1979–1981	b (*a)	average of two methods: #2- estimates generated from linear and ratio interpolation and extrapolation of USGS data via various methods, and #3- SWFWMD citrus groundwater use normalized to the whole county
1982–1984, 1986–1989, 1991–1994, 1996–1997	b (*a)	average of two methods: #3- SWFWMD citrus groundwater use normalized to the whole county, and #4- sum of available WMD data (SJRWMD and SWFWMD) normalized to the whole county
1985, 1990, 1995	b (*a)	average of three methods: #2- estimates generated from linear and ratio interpolation and extrapolation of USGS data via various methods, #3- SWFWMD citrus groundwater use normalized to the whole county, and #4- sum of available WMD data (SJRWMD and SWFWMD) normalized to the whole county
1998–2002	a	sum of annually reported (SWFWMD and SJRWMD) and linear and ratio interpolated (SFWMD) data
2003–2010	a	sum of annually reported (SWFWMD) and linear and ratio interpolated (SFWMD) data
Seminole County: Groundwater use estimation accuracy for citrus		
Time period	**Data Accuracy**	**Method/Comment**
1950–1956	n/a	not estimated
1957–1977	c	average of two methods: #1- linear extrapolation of SJRWMD citrus groundwater use data, and #2- exponential extrapolation of the ratio of estimated citrus groundwater use to FASS citrus tree count; curve based on SJRWMD citrus groundwater use data from 1978-1999
1978–1999	a	annual SJRWMD and USGS citrus groundwater use data
2000–2010	b (*a)	extrapolated using linear and ratio methods with data in adjacent years
a = most accurate/most reliable/less data filling, d = less accurate/less reliable/more data filling		
*relative to this county only, this data is accurate based on the first rating; relative to other counties' citrus data, it is more similar to the asterisked accuracy rating.		

APPENDIX H: GOLF GROUNDWATER USE ESTIMATION DATA ACCURACY

Table H-1 shows the relative accuracy of groundwater use estimates for each time period in this project. This is a qualitative table that ranks the accuracy of each time period in each county relative to itself, as well as relative to other counties. Rankings can be assumed to be comparable across counties. However, asterisked rankings should be used to compare between counties when present.

Table H-1. Relative accuracy of agricultural (non-citrus) groundwater use estimations and methods

Lake County: Groundwater use estimation accuracy for golf courses		
Time period	**Data Accuracy**	**Method/Comment**
1957–1979	n/a	no data
1980–1984	b	average of adjacent years
1985–2009	a	annual data from SJRWMD, normalized to whole county
2010	b	average of adjacent years
Orange County: Groundwater use estimation accuracy for golf courses		
Time period	**Data Accuracy**	**Method/Comment**
1957–1977	n/a	no data
1978–1984	c	average of SJRWMD and SFWMD data, each extrapolated based on slope of adjacent years
2000–2010	a	average of annual data from SJRWMD normalized to county and interpolated/filled data from USGS and SFWMD
2010	b	average of adjacent years
Osceola County: Groundwater use estimation accuracy for golf courses		
Time period	**Data Accuracy**	**Method/Comment**
1957–1979	n/a	no data
1980–1989	b (*c)	nearest data reports zero groundwater use, so cannot estimate until data greater than zero.
1990–2010	a (*b)	estimation based on interpolated and extrapolated acreages multiplied by groundwater use per acre; very few reliable data points; high level of uncertainty
Polk County: Groundwater use estimation accuracy for golf courses		
Time period	**Data Accuracy**	**Method/Comment**
1957–1976	n/a	no data
1977–1984	c	linear extrapolation based on adjacent years
1985–1999	a (*b)	average of included USGS data in adjacent years
2000–2010	b	SWFWMD data, normalized to county

Seminole County: Groundwater use estimation accuracy for golf courses		
Time period	**Data Accuracy**	**Method/Comment**
1957–1979	n/a	no data
1980–1985	b	average of adjacent years
1986–2009	a	annual data from USGS estimates for whole county
2010	b	average of adjacent years
a = most accurate/most reliable/less data filling, d = less accurate/less reliable/more data filling		
*relative to this county only, this data is accurate based on the first rating; relative to other counties' golf data, it is more similar to the asterisked accuracy rating. This data is highly estimated.		

APPENDIX I: ACCESSORY DESCRIPTIVE TABLES AND FIGures

Table I-1 shows a compiled average mgd groundwater use per water use type by county for the CFCA. The “avg1980–2010” and “avg1990–2010” rows are displayed for a comparative look at the influence of golf in each county in the last two or three decades. This is necessary because golf groundwater use data was not available in years prior to 1977, and thus was not comparable to other water use types.

Table I-1. CFCA estimated groundwater use summarized by decade

Historical annual groundwater use estimates by water use type (in mgd).															
County	**Lake**			**Orange**			**Osceola**			**Polk**			**Seminole**		
Year	**Ag**	**Citrus**	**Golf**	**Ag**	**Citrus**	**Golf**	**Ag**	**Citrus**	**Golf**	**Ag**	**Citrus**	**Golf**	**Ag**	**Citrus**	**Golf**
avg1950s	20.9	27.3	n/a	14.5	8.9	n/a	3.1	11.1	n/a	4.4	21.1	n/a	24.7	10.8	n/a
avg1960s	33.5	43.9	n/a	13.6	9.0	n/a	4.8	17.1	n/a	11.8	40.5	n/a	28.6	12.5	n/a
avg1970s	44.7	56.8	n/a	31.7	21.4	3.2	4.7	16.7	n/a	20.4	72.7	3.0	18.8	9.2	n/a
avg1980s	22.0	39.3	1.1	55.6	34.9	4.3	5.6	19.9	0	28.8	74.9	3.8	18.4	4.7	3.8
avg1990s	13.8	28.4	1.2	21.9	12.0	5.9	6.4	22.7	0.6	29.3	93.0	5.5	4.9	2.6	3.3
avg2000s	7.6	16.9	4.7	16.8	10.7	8.6	10.1	35.8	0.4	32.4	84.8	4.6	6.0	5.7	1.5
Avg of all years	23.8	36.2	n/c	27.0	17.0	n/c	6.1	21.8	n/c	23.5	70.3	n/c	15.7	7.1	n/c
avg1980-2010	14.2	27.9	2.4	31.1	18.9	6.3	7.3	26.1	0.4*	30.1	83.8	4.6	9.6	4.4	2.8
avg1990-2010	10.5	22.4	3.0	19.4	11.3	7.3	8.2	29.0	0.5	30.7	88.1	5.0	5.4	4.2	2.3
* = zero groundwater use reported in Osceola County for 1980s golf															
n/a = not applicable															
n/c = not comparable															

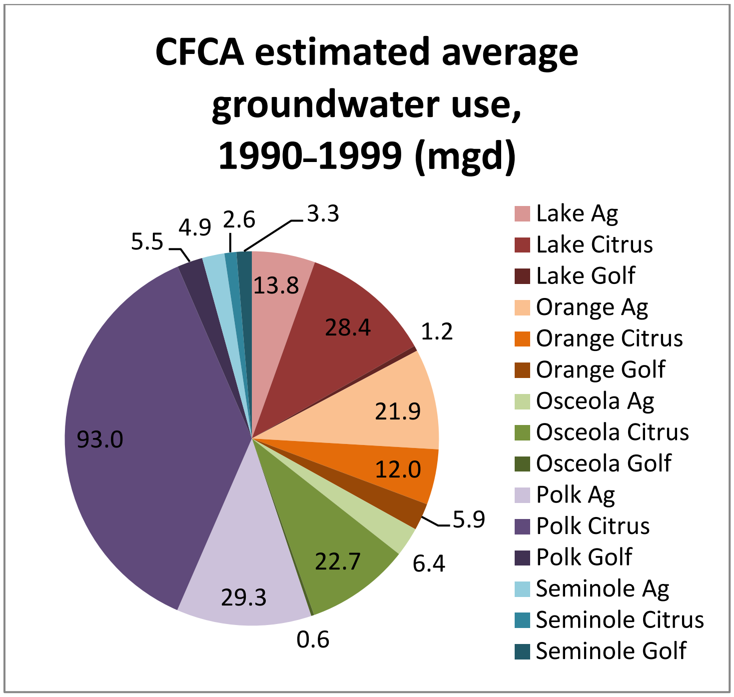

Figure I-1. In the 1990s, Polk County used the most groundwater, especially Polk citrus; Lake County used significant groundwater for citrus

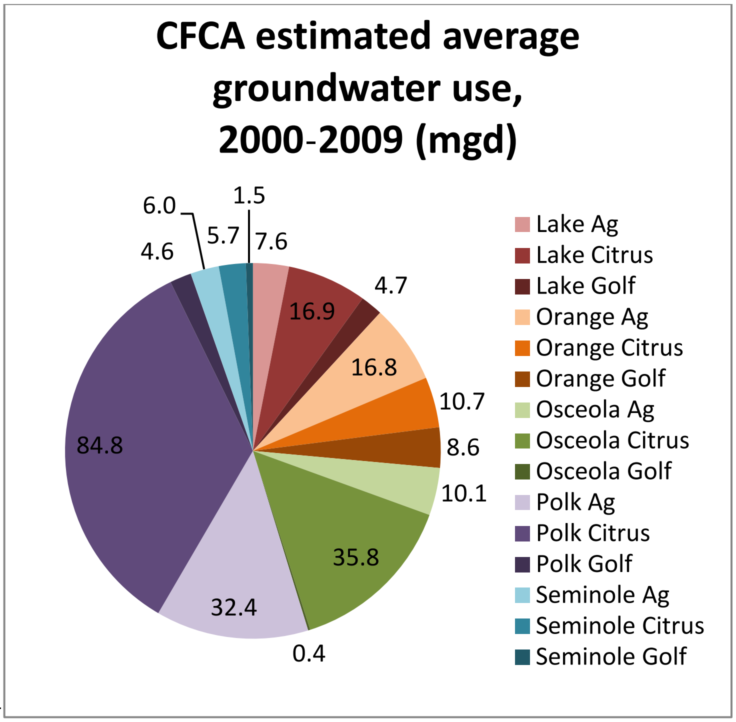

Figure I-2. Polk County, particularly Polk citrus, is currently the main user of groundwater in the CFCA (Osceola and Orange counties use the next highest amounts, respectively)