Irrigation and Water Use Reporting in the Tennessee Valley Region of Alabama

by

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Abstract

Irrigation is the largest consumptive use of water in the United States. Accurate monitoring of water use for irrigation is critical for a state to sustainably manage its water resources. Federal programs provide valuable information for states to utilize, but individual states may develop their own program to supplement those federal programs. In 1993, Alabama passed the Water Resources Act, requiring irrigators with the capacity to withdraw more than 100,000 gallons per day to apply for a Certificate of Beneficial Use (COU) with Alabama's Office of Water Resources for each pump that is withdrawing water and report their use annually. Recent studies have revealed issues with the effectiveness of Alabama's COU program. This study investigated CP irrigation in the Tennessee Valley region in northern Alabama for the years 2011 to 2015 to determine whether CP irrigators were applying for COUs and reporting water use as required by the program. The study found that CP irrigation increased substantially (194 to 324; +67.0%) for the study period. However, the number of pumps registered for irrigators did not change (77) throughout the study period. Furthermore, an attempt to connect CP irrigation sites to their appropriate COU was not possible due to issues with quality control on data collection. The results of the study are compared to the Wiregrass region in southeastern Alabama to build towards a comprehensive understanding of the effectiveness of Alabama's COU program.

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Thank you to my family, for supporting me and encouraging me to do the right thing at every step of the way.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AL-OWR	Alabama Office of Water Resources
AL-SOS	Alabama Secretary of State
COU	Certificate of Beneficial Use
CP	Center Pivot
GIS	Geographic Information System
MGD	Million Gallons per Day
NAIP	National Agricultural Imagery Product
NDVI	Normalized Difference Vegetation Index
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Chapter 1: Introduction

A state must be able to efficiently monitor water usage to sustainably manage its water resources. Federal water use monitoring programs administered by U.S. agencies are utilized by states for water management and planning, but many states develop their own programs for monitoring water use. This is done to supplement information from federal agencies and to provide information specific to the needs of the state. Irrigation water use for agriculture should be carefully examined by federal and state water use monitoring programs because irrigation is the largest single consumptive use of water within the United States (Dieter et al. 2018).

The state of Alabama has a water use monitoring program managed by the Office of Water Resources (AL-OWR) where irrigators withdrawing more than 100,000 gallons per day (GPD) must register a Certificate of Beneficial Use (COU) and report their water use, but recent studies of the Wiregrass region in southeastern Alabama detected several problems with the program (Barbre 2017; Chaney 2017). Only 54.0% of water use reports out of the total number of irrigators registered in the region reported use, with only 24.0% of center pivots (CPs) identified in the region that were able to be connected to an individual irrigator. Calculated depths of application for CP irrigation in the region ranged from 0.5 to 212.6 inches of water applied per acre (Chaney 2017). Additionally, the Alabama legislature recently passed a tax credit for irrigation systems providing up to $50,000 in tax assistance (Justia US Law 2018). The economic pressures to increase irrigation within the state and the issues documented with Alabama's water use monitoring program within the Wiregrass region create a need for further evaluation of the program to ensure sustainable use of the state's water resources for the future.

This study will expand the investigation into Alabama's water use monitoring program by evaluating the Tennessee Valley region in northern Alabama to determine whether water monitoring issues are present in other areas of the state. Center pivot (CP) irrigation specifically is the focus of this study as it is perceived to be the predominant method of crop irrigation by stakeholders. The primary research questions for this project are as follows:

1. How many CP sites are in the Tennessee Valley region of Alabama?
2. How does the change in the number of CP sites in the Tennessee Valley compare to the Wiregrass region of Alabama?
3. How many CP sites in the Tennessee Valley can be associated with a COU?
4. How does the number of CP sites with a COU in the Tennessee Valley compare to the Wiregrass?
5. How does the water use reporting in the Tennessee Valley compare to the Wiregrass?
6. How does the reported volume of water withdrawn for center pivot irrigation in the Tennessee Valley compare to the water use values estimated by the United States Department of Agriculture's Farm and Ranch Irrigation Survey?

Chapter 2: Irrigation Water Use Monitoring

Federal Water Monitoring Programs

The U.S. government agencies that are the most involved in irrigation monitoring are the United States Department of Agriculture (USDA) and the United States Geological Survey (USGS). The USGS collects national water use data and publishes a running circular report every five years titled "Estimated use of water in the United States" through the National Water Use Science Project, with the most recent publication from 2015 (Dieter et al. 2018). The USDA's National Agricultural Statistics Service publishes the Farm and Ranch Irrigation Survey (USDA) every five years, with the most recent publication from 2013. The Farm and Ranch Irrigation Survey is produced from the Census of Agriculture, which is a self-reporting data collection program conducted every five years nationally (USDA NASS 2018). These bi-decadal, nationwide reports are valuable to state agencies and researchers, but may be conducted too infrequently to address the needs of individual states.

It is important to note that the results of any irrigation monitoring program depend on the agency conducting the survey, the scale of the survey, the classifications used, and the data available. The USDA and USGS both publish data estimating irrigation water use and irrigated area, but their results tend to vary. In 2013, the USDA estimated approximately 101,000 irrigated acres in Alabama, but in 2015 the USGS estimated as many as 189,000 irrigated acres (Vilsack and Clark 2014; Dieter et al. 2018). It is possible that this growth occurred within the two year difference in publications; however, it seems unlikely. Differences in categorical organization between the USDA and USGS may help explain some of the conflicting results, but concerns regarding accuracy remain.

The estimates published in the USDA's Farm and Ranch Irrigation Survey only concern agricultural and horticultural uses of irrigation, whereas the USGS includes golf courses in its estimates and does not distinguish between agricultural and non-agricultural uses of irrigation (Dickens et al. 2011; Vilsack and Clark 2014). The classifications used to estimate irrigated area are different among both agencies as well. The USDA has multiple levels of classification for irrigated acreage estimates, with the primary organization between gravity systems, sprinkler systems, and micro-irrigation. The USDA then breaks down each primary organization by system type. For example, sprinkler systems are divided into center pivots, linear move towers, permanent sprinklers, side roll or other mechanical systems, traveling guns, hand move systems, and all other types. Center pivots, linear move towers, and permanent sprinklers are then broken down even further into operating pressure categories (Vilsack and Clark 2014). However, the USGS only distinguishes between sprinkler, surface (gravity), and micro-irrigation in its irrigation estimates. Furthermore, the USDA estimated over 4,000 acres were irrigated by gravity systems and just under 10,000 acres irrigated by micro-irrigation in its 2013 report, while the USGS estimated 0 irrigated acres for surface delivery and micro-irrigation systems in its publication for 2015 (Vilsack and Clark 2014; Dieter et al. 2018).

State Water Use Reporting and Metering Programs

Some states may utilize a water use reporting program to supplement the data from these national publications. A brief survey of the 48 contiguous U.S. states was conducted by Barbre (2017) and Chaney et al. (2018) to determine which states had some form of water use reporting program, the requirements for the program, and to understand how each state monitors and enforces their program. The results of the survey indicate that a majority of states have water use reporting programs, excluding West Virginia. Most of the water use reporting programs involve either a permitting or registration process, where the state sets a withdrawal threshold and any users withdrawing at or above that threshold must register their use or apply for a permit with the state (Barbre 2017; Chaney et al. 2018). It appears that enforcement of compliance with water use reporting programs is an issue in many states, as 21 of the 48 states surveyed, including Alabama, had little or no enforcement of their water use reporting program.

The withdrawal threshold for reporting water use will vary by the needs of individual states, but the frequency of reporting tends to be annual. For example, Virginia requires annual reporting of water withdrawals greater than 10,000 GPD (Paylor and Ward 2017). Arkansas requires irrigators withdrawing more than 50,000 GPD report their water use annually (FTN Associates 2017). Illinois mandates that anyone withdrawing more than 100,000 GPD report their usage annually (Illinois Department of Natural Resources 2018). Kansas requires water rights holders to fill out annual water reports (Turner et al. 2011). Irrigators must apply for a permit in Mississippi before any withdrawals occur at all (Justia US Law 2017 Mississippi Code).

States with severe water over-allocation issues or that are involved in water use conflicts with other states may choose to meter agricultural withdrawals. In 2003, Georgia passed House Bill 579, giving the Georgia Soil and Water Conservation Commission the authority to install water meters at agricultural sites across the state, with over 10,000 meters installed by 2010 (Torak and Painter 2013). The Texas Water Development Board’s voluntary metering program collected water use on over 80,000 irrigated acres actively metered in 2007 (Turner et al. 2011).

Other states that have adopted irrigation metering programs include Kansas, Nebraska, and Oklahoma to reconcile interstate water conflicts (Turner et al. 2011).

GIS and Remote Sensing for Water Monitoring

Several states surveyed by Barbre (2017) and Chaney et al. (2018) indicated that they use some form of geographic information systems (GIS) or remote sensing for monitoring water withdrawals. Mapping irrigated areas allows states and federal agencies to quantify changes in irrigation water use over time, without requiring installation and maintenance of water meters. This is because changes in irrigated area directly relate to changes in irrigation water use, as documented within Arkansas and Texas (Turner et al. 2011; FTN Associates 2017).

There are two major approaches to mapping irrigated areas: digital image classification and manual interpretation. Digital image classification primarily uses satellite data, whereas manual interpretation typically uses aerial imagery. Digital classification studies extract irrigated areas from satellite imagery through time-series analysis of spectral signatures, such as the Normalized Difference Vegetation Index (NDVI) (Lenney et al. 1996; Beltran and Belmonte 2001; Ozdogan and Gutman 2008; Pervez and Brown 2010). There are several benefits to the digital classification method: a long historic record of data (i.e., Landsat), the ability to take many images within a single growing season, and a less time-intensive process than manual interpretation (Ozdogan et al. 2010). The disadvantage of digital classification is that vegetation indices such as NDVI cannot distinguish between irrigated and non-irrigated cropland for humid and densely vegetated areas such as the Eastern United States (Ozdogan et al. 2010). Manual interpretation requires an analyst to manually digitize polygons within a GIS based on a visual inspection of imagery (Finkelstein and Nardi 2016). The manual interpretation method is still the most accurate for humid areas with dense vegetation, despite continual advances in satellite imagery sensing and image processing techniques (Ozdogan et al. 2010).

For mapping center pivot irrigation in the Northern Atlantic Coastal plain, the USGS used manual interpretation of 1-meter National Agricultural Imagery Product (NAIP) data available from the United States Department of Agriculture Farm Service Agency (Finkelstein and Nardi 2016). The methodology for identifying CP systems was based on the visibility of circular patterns, wheel tracks, and the presence of the pivot "arm" or mainline. The visual interpretation method has been used by researchers in both Nebraska and Georgia to map changes of irrigated acreage across time (Litts et al. 2001; Millington 2015). Litts et al. (2001) used the USDA National Aerial Photography Program, the precursor to the NAIP program with a spatial resolution between 1 and 1.5 meters, in Georgia and Millington (2015) used the 1-m NAIP data in Nebraska. The studies by Litts et al. (2001) and Millington (2015) also used nearly identical criteria as the USGS publication for identifying center pivot systems.

In Alabama, the Office of Water Resources worked with researchers at the University of Alabama in Huntsville as well as Auburn University to document the change in center pivot irrigated acreage across the state (Handyside 2014; Barbre 2017). Handyside (2014) compared the changes in irrigated acreage by county for the years 2006, 2009, 2011, and 2013. Barbre (2017) documented the growth in irrigated acreage in the Wiregrass Region specifically for the years 2011, 2013, and 2015.

Alabama's Certificate of Beneficial Use (COU) Water Use Reporting Program

In Alabama each irrigator that has the capacity to withdraw more than 100,000 GPD is required to register a COU for each pump or diversion that is withdrawing water (Alabama

Department of Economic and Community Affairs Office of Water Resources 2015; Justia US Law 2017 Code of Alabama). Irrigators must submit annual water use reports for each pump registered to a COU. It is important to note that multiple irrigation systems may be supplied by a single pump in certain cases. When irrigators apply for a COU in Alabama, they provide information including but not limited to the owner name (i.e., COU holder), latitude and longitude of the pump, a map of the property and proximity of the water source, and whether the withdrawal is from surface or groundwater (Alabama Department of Economic and Community Affairs Office of Water Resources 2015). However, there is no enforcement of the program by the state as there are no penalties for irrigators who choose not to participate (Barbre 2017).

Chapter 3: Study Area - Tennessee Valley

For the purpose of this study, the Tennessee Valley Region of Alabama is defined as the six counties that comprise the majority of the low-lying river valley north and west of the Cumberland Plateau region of Alabama that contain the Highland Rim physiographic province (Tew 2006**.** These counties are Colbert, Lauderdale, Lawrence, Limestone, Madison, and Morgan (Figure 1). This area was selected because of the high concentration of center pivot systems detected by Handyside (2014) in the region.

The six counties of the Tennessee Valley Region cover a total of 2,290,902 acres. Approximately 12.9% of the region is developed or urban areas, 30.9% forest, 13.7% cropland, 27.4% pasture or hay, and 15.1% is some other land use type (Table 1).

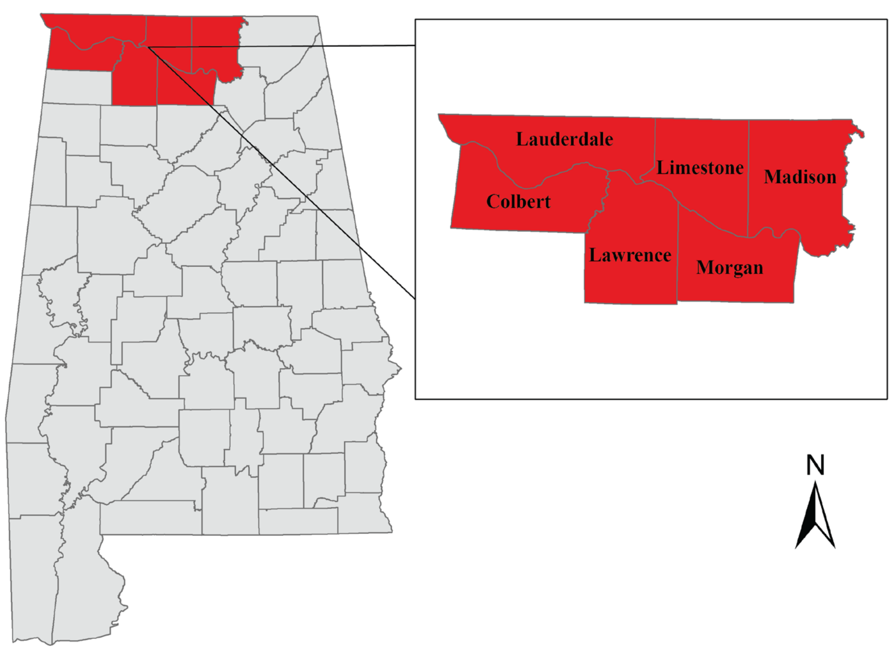

Figure 1: Tennessee Valley Study Area.

Table 1: Land use land cover percentage (%) by county. The land cover statistics have been computed form the National Land Cover Dataset 2011. Source: Multi-Resolution Land Characteristics Consortium (2018).

County	Area (Acres)	Urban/ Developed (%)	Forest (%)	Cultivated Crops (%)	Hay/Pasture (%)	Other (%)	**Total (%)**
Colbert	343,595	9.8	41.2	11.3	18.3	19.4	100.0
Lauderdale	394,687	10.7	31.9	12.3	30.6	14.5	100.0
Lawrence	395,012	6.0	34.4	11.6	31.0	17.0	100.0
Limestone	349,607	9.7	24.8	18.6	33.6	13.3	100.0
Madison	463,805	25.0	23.1	20.2	19.7	12.0	100.0
Morgan	344,196	13.3	32.1	6.2	33.1	15.3	100.0
Total	2,290,902	12.9	30.9	13.7	27.4	15.1	100.0

Chapter 4: Research Methods

This project was segmented into multiple stages to investigate irrigated agriculture and Alabama's water use reporting program in the Tennessee Valley. The COU data was provided by the AL-OWR along with the annual water use reports submitted by the COU holders. The available data included owner name, county, the location of the pump in latitude/longitude, whether the water source was surface or groundwater, the name of the water source, and the average daily use for each month of the year in millions of gallons per day (MGD) (Table 2). The location maps that irrigators submit to the AL-OWR were not available in digital format and were not provided. A general outline of this study is provided in Figure 2, with specific workflow details and data sources provided in Figure 3.

Table 2: Example Certificate of Use (COU) data provided by the Alabama Office of Water Resources.

Source Type	Name	Certificate Number	County	Owner Name	Pump Name	Lat.	Long.	Source or Aquifer	Jan (MGD)	Feb (MGD)	Mar (MGD)	Apr (MGD)
GW	Big Creek	111	Lee	Aubie Farms	Well No. 1	32.60	85.49	Coastal Plain	0	0	0.5	1
SW	Big Creek	112	Lee	Samford Sod Farm	Pond No. 1	32.63	85.51	Coastal Plain	0	0	0.3	1.5

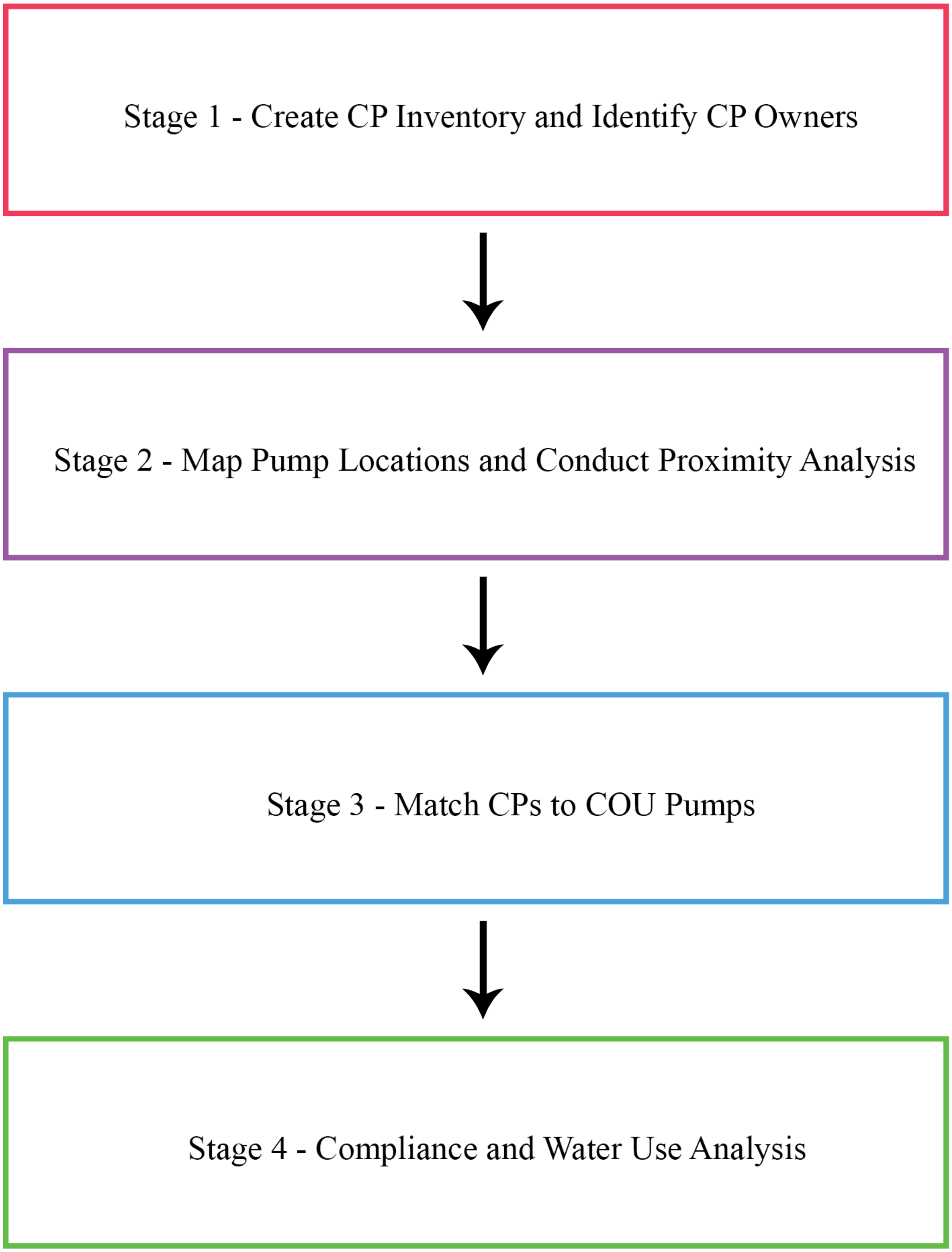

Figure 2: General study methodology outline.

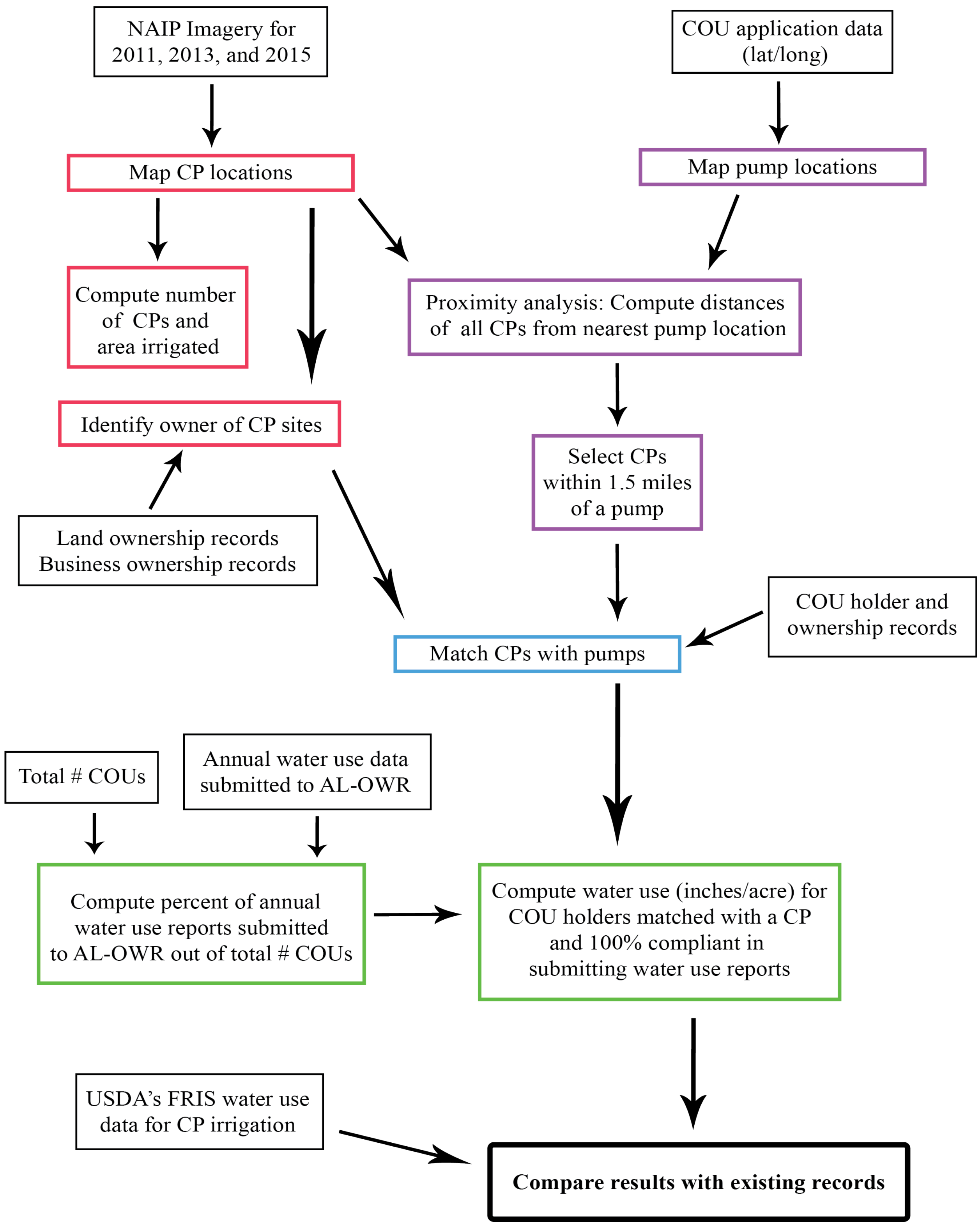

Figure 3: Detailed study workflow.

Inventory of Center Pivot Irrigation Systems

National Agricultural Imagery Program data collected by the USDA Farm Service Agency are available for the contiguous U.S. for two-year intervals at 1-meter spatial resolution (USDA Farm Service Agency 2018). The Watershed Boundary Dataset published by the USGS delineates catchment areas within the United States defined by hydrologic unit codes (HUCs) (USGS 2019). The NAIP data was imported into ESRI ArcGIS 10.4 and used to map CP systems for the years 2011, 2013, and 2015 (Figure 4). The watershed areas defined by the HUC12 were imported into ArcGIS and overlaid onto the NAIP data to guide the search for CPs. The NAIP data was chosen due to its high spatial resolution, but also to allow accurate comparison to studies conducted in the Wiregrass region by Barbre (2017) and Chaney (2017)

The manual interpretation approach was used for identification of center pivot sites and expanded upon from existing studies (see Litts et al. 2001; Handyside 2014; Millington 2015; Finkelstein and Nardi 2016). The visual guidelines defined in the literature for manual interpretation include the circular shape created by the irrigated crops and the wheel tracks, and the identification of the horizontal span pipes and the vertical tower in the center. Visual examples of the primary guidelines as well as additional criteria for identifying CPs are provided in Appendix 1. Once a CP system was positively identified, a circular polygon extending from the center tower to the end of the horizontal spans was drawn. Some CPs clearly had end guns irrigating beyond the boundary of the horizontal spans, so the polygon was drawn from the center tower to the end of the irrigated area for these.

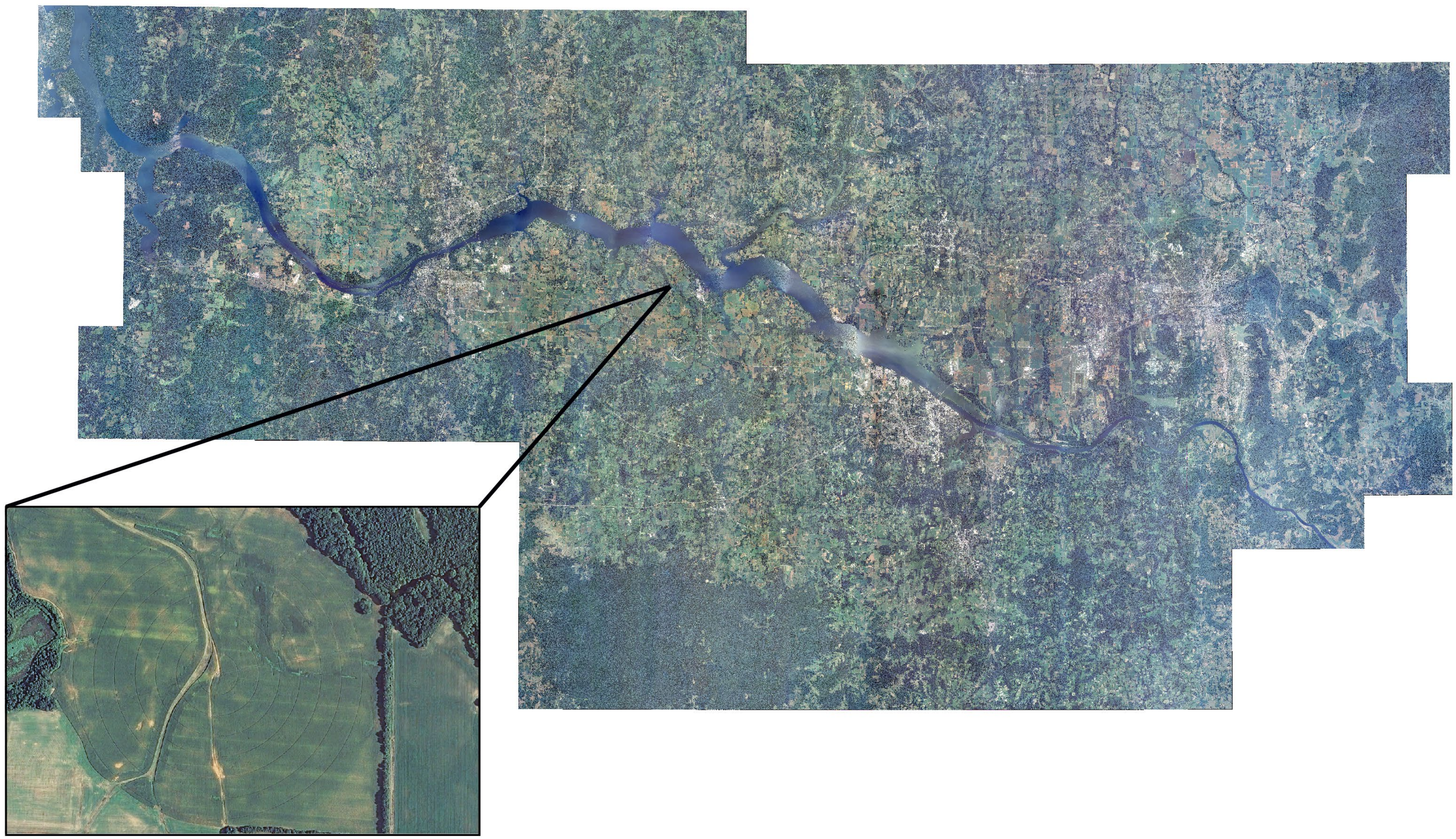

Figure 4: 2011 NAIP imagery of the Tennessee Valley region of Alabama.

Identifying Center Pivot Owners

Tax parcel data available through county tax assessor offices and web GIS platforms was used to link a center pivot system to the owner of the property on which it is located (Figure 5). Using a spatial join in ArcGIS 10.4, the ownership information for tax parcels intersecting a center pivot polygon was appended to the CP polygon attribute data tables. Some CPs had their areas span across multiple parcels. When this occurred, all parcels lying under the CP were inspected. Most of the pivots spanning multiple parcels were owned by the same entity, but multiple parcels with different owners were cross-checked against the business records maintained through the Alabama Secretary of State's (AL-SOS) website. Several parcels turned out to be owned by the same entity registered under different names. The landowner with the most area under irrigation by a CP was taken to be the owner of the CP in cases where no definitive conclusion could be drawn.

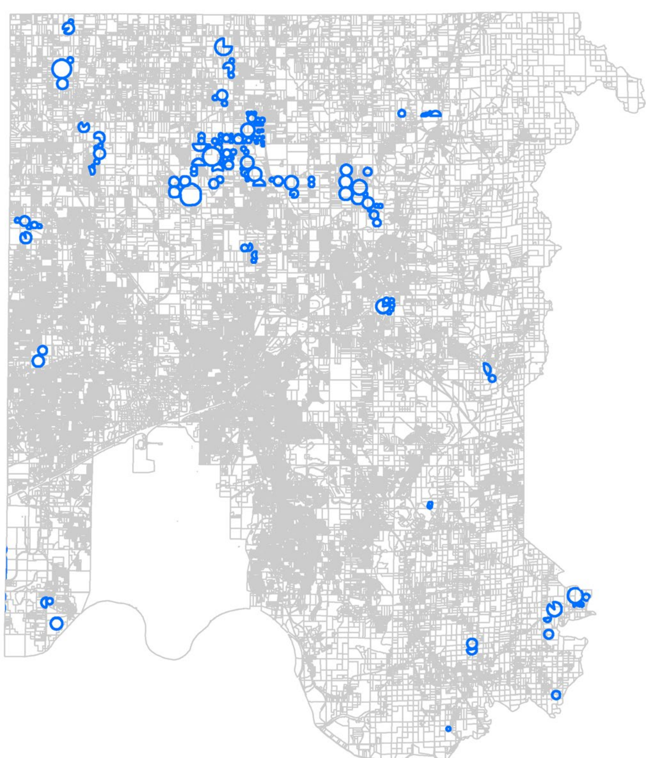

Figure 5: Pivot polygons (blue) overlaid on tax parcel data (grey for Madison County.

Proximity Analysis of Center Pivots and Pumps

A major assumption used early in this study was that CPs could easily be matched to their respective COU pumps based on proximity. This proved to be false as a high number of duplicate pump coordinates were provided for separate pumps (Table 3). It is not clear whether supplemental information such as the location maps submitted to AL-OWR would have helped, as the instructions on the COU application do not specify that the map include the pump location or specific sites supplied by the pump.

Alabama Agricultural Experiment Station experts estimate the maximum distance between a pump and pivot tower to be approximately 1.0 miles (Dr. Philip Chaney, Auburn University Department of Geosciences, personal communication). This distance was extended to 1.5 miles to accommodate for potential problems resulting from the lack of positional accuracy with the COU pump locations. The latitude and longitude of the COU pump coordinates were used to import the pump locations into ArcGIS. Buffer zones extending 1.5 miles were created around pump locations to select center pivots that were within a reasonable distance of the COU pumps for further investigation. Only CPs within this 1.5 miles buffer zone were used for developing compliance information and for the final water use analysis.

A buffer analysis was then conducted to calculate the distances of all CPs from the nearest pump. This was done to gauge compliance with the COU program as CPs that are great distances from any registered pump are likely being supplied by an unregistered pump. This process involved creating buffer zones around the COU registered pumps at half-mile intervals and identifying the total number of center pivots that lie inside and outside of the buffer zone.

Table 3: Duplicate location reporting for COU Holders with multiple COU.

Owner ID	Pumps	Duplicate Lat/Long
1	2	1
3	3	2
5	5	2
6	19	4
7	5	1
8	2	1
11	13	3
12	3	0
13	5	0
15	10	1
17	3	0
Totals	**70**	**15**

Matching Center Pivots with Pumps

A search of the AL SOS was conducted with the owner information of each COU to provide additional possible names for tax parcels that could be registered under that COU holder. This was necessary because a hypothetical COU holder such as John Smith Farms Inc. could own land under the name John Smith, Smith Farms, or under another name entirely if John Smith Farms Inc. has multiple business members. The CPs that were within the 1.5 miles buffer radius of a COU pump then had their landowner information inspected to match them with the correct pumps for estimating water use. Once the CPs were matched to their correct COU pumps, the ratio of CPs matched to COUs out of the total number of CPs was calculated.

Compliance and Water Use Analysis

Several compliance indicators were investigated for this study in addition to the ratio of CPs matched to COUs. The percent of annual water use reports submitted out of the total number of registered COUs, the percent of COUs that were reported out of the total number of COUs matched to CPs, and the percent of COU holders matched to CP irrigation who were 100% compliant in reporting water use for all of their COUs were investigated. The information developed in this report is useful for gauging irrigator compliance with the COU holder program and for comparing data to the Wiregrass studies; however, it must be noted that until the COU program requires accurate location reporting of the COU registered pumps that any compliance information developed other than the percent of annual water use reports submitted out of the total number of registered COUs cannot be completely accurate.

The average amount of water applied per acre was calculated and compared to the USDA Farm and Ranch Irrigation Survey published average application depths for center pivot irrigation in Alabama for the purpose of gauging the accuracy of the COU water use reports submitted in the Tennessee Valley. This was accomplished by multiplying the reported average daily water use in each month by the number of days in that month and then summing the values for each month in the year to get the total reported water use for that year. The total reported use in units of millions of gallons was converted to acre-inches by multiplying by 36.827. Once the total reported use was converted to acre-inches, the depth of application in inches per acre can be calculated for each COU holder by dividing by the number of acres under irrigation. Note that the USDA first published estimates on average depth of application for center pivot irrigation in the 1998 Farm and Ranch Irrigation Survey, so estimates are available for the years 1998, 2003, 2008, and 2013. Only data from COU holders who were 100% compliant in submitting water use reports for a given year was used for the final accuracy assessment. This was done because these provided the only complete sets of data for making comparisons.

Chapter 5: Results and Discussion

Center Pivot Systems and COUs in the Tennessee Valley

This study identified a total of 194 center pivots covering 20,341 acres in 2011; this number increased to 263 CPs (25,998 acres) in 2013, and increased again to 324 (30,417 acres) in 2015 (Figures 6, 7, 8, and 9). This corresponds to a growth of approximately 67.0% for the number of CPs and a 49.5% growth in total CP irrigated acres for the study period (Tables 4 and 5). Only two center pivots appear to have been moved from their original position in 2011 for all three years surveyed in the Tennessee Valley (Figure 10).

The COU records provided by the AL-OWR contained 99 COUs registered for irrigation purposes belonging to 29 COU holders. The COU data provided by AL-OWR did not describe the specific purpose of irrigation for each COU holder (nursery, golf course, crop, etc.), but the name provided often indicated the purpose (e.g. Auburn Nurseries, Auburn Golf Course, Auburn Farms). The owner name was then used to determine that 12 COU holders (22 COUs) were most likely not involved with CP irrigation and removed from the analysis. Eleven of the 17 remaining COU holders had multiple COUs registered, with the highest number of COUs belonging to one COU holder being 19. The number of COU pumps did not change for the study period; consequently, the average number of CPs per COU pump increased from 2.52 (2011) to 4.21 (2015) by the end of the study. This pattern suggests that the newer CPs are being supplied by additional COU pumps that have not been registered with the state.

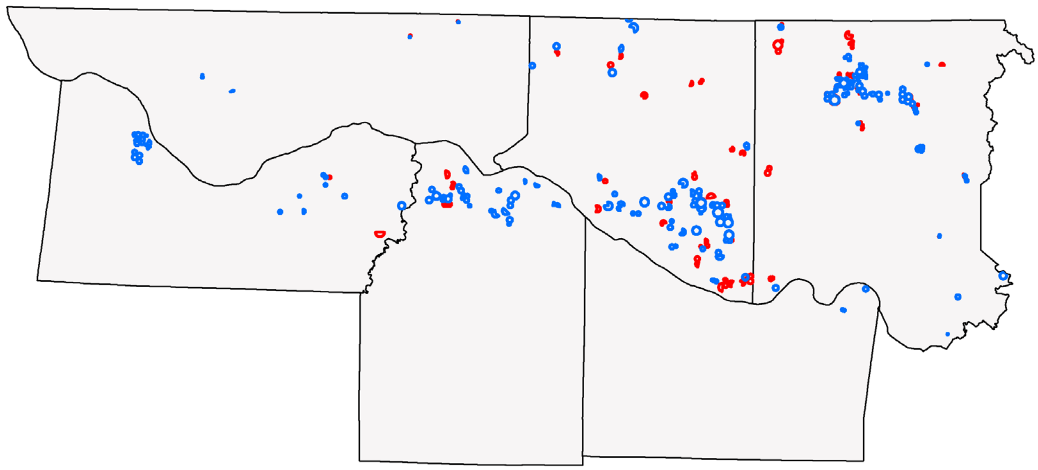

Figure 6: Change in CPs from 2011 (blue) to 2013 (red).

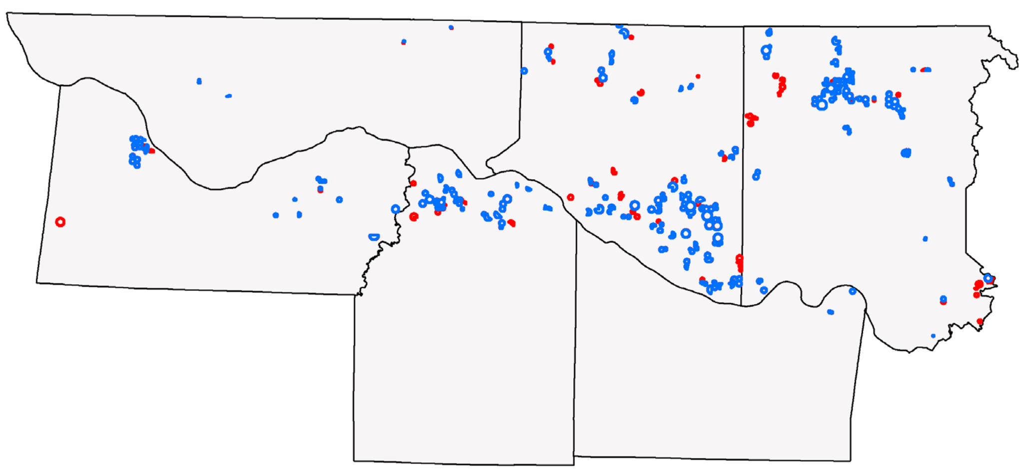

Figure 7: Change in CPs from 2013 (blue) to 2015 (red).

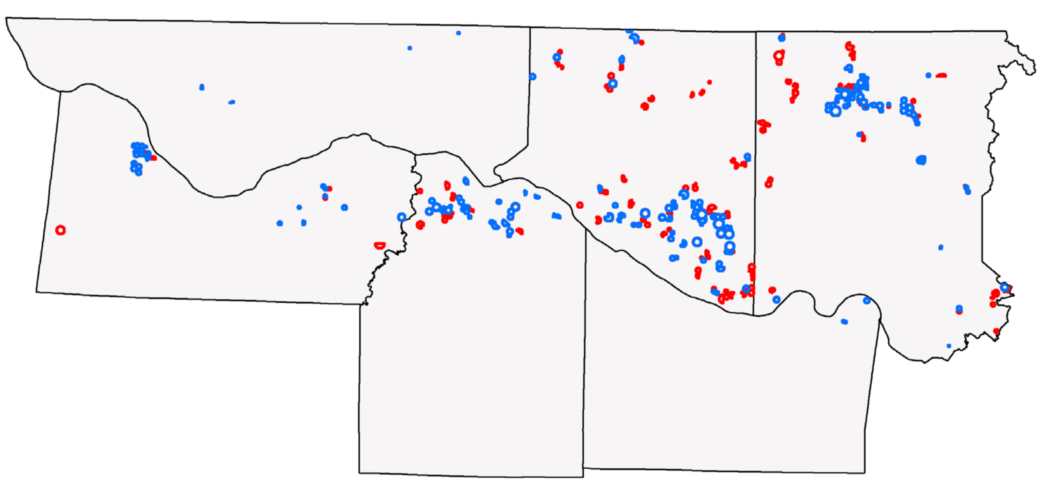

Figure 8: Change in CPs from 2011 (blue) to 2015 (red).

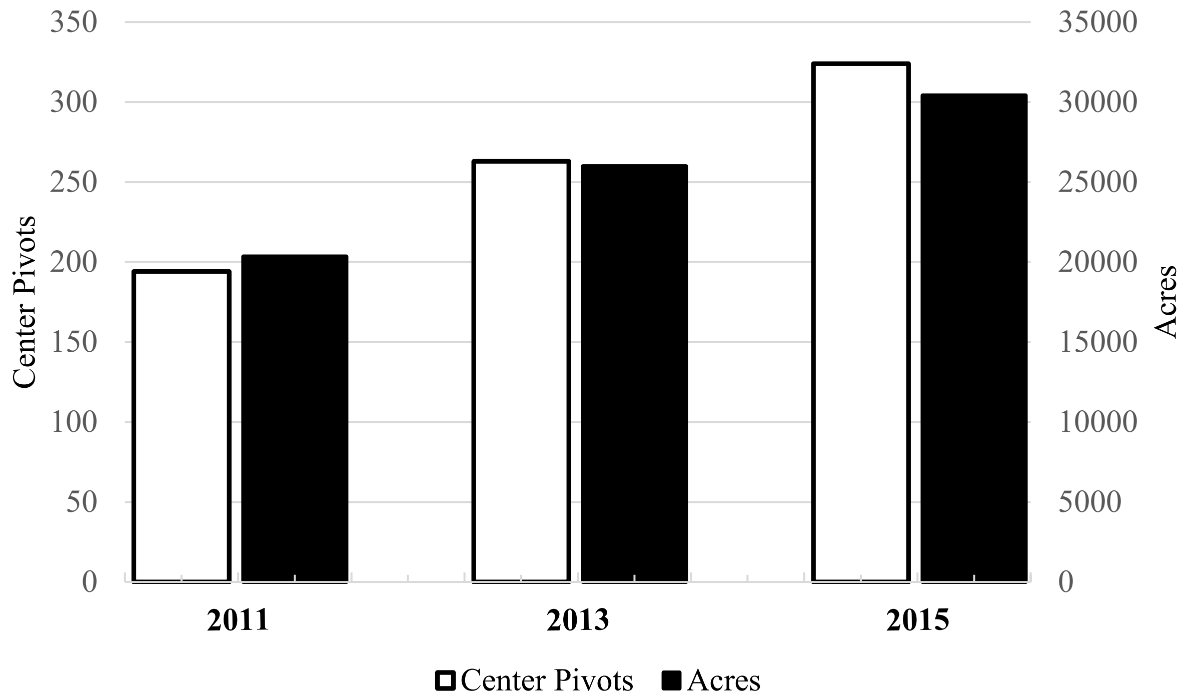

Figure 9: Number of CPs and corresponding acres for the three study years.

Figure 10: Only two CPs moved from 2011 (blue) to 2013 (red).

Comparison of Center Pivot Growth in the Tennessee Valley and Wiregrass Regions

The Wiregrass region had over twice as many total CPs identified each year as the Tennessee Valley region for the study period; however, the total number of acres under CP irrigation in each region for each year was closer in magnitude (Table 4). The number of CPs in the Tennessee Valley grew at a faster rate (+12.6%) than in the Wiregrass for the study period (Table 5). This trend was not consistent with the rate of growth of irrigated acres in each region as the Tennessee Valley grew slightly slower (-4.1%) than the Wiregrass in percent of total irrigated acres for the study period. A detailed comparison of metrics between all CPs identified in the Tennessee Valley and Wiregrass across the study years is provided in Appendix 2.

Table 4: Number of CPs identified in each region for each year and corresponding acres.

	Tennessee Valley		Wiregrass	
	CPs	Acres	CPs	Acres
2011	194	20,341	461	23,648
2013	263	25,998	582	29,350
2015	324	30,417	712	36,326

Table 5: Percent change in CPs and CP acres for each region

	Tennessee Valley		Wiregrass	
	Change in CPs (%)	Change in Acres (%)	Change in CPs (%)	Change in Acres (%)
2011 - 2013	35.6%	27.8%	26.2%	24.1%
2013 - 2015	23.2%	17.0%	22.3%	23.8%
2011 - 2015	67.0%	49.5%	54.4%	53.6%

Proximity Analysis of Center Pivots and COUs

The results of the buffer analysis appear to be mixed but suggest compliance issues for both the Tennessee Valley and Wiregrass. For the 2015 study year, 50.9% (165) of CPs in the Tennessee Valley were within 1.5 miles of a registered pump, while 27.8% (198) of CPs in the Wiregrass were within 1.5 miles of a registered pump (Figure 11). This seems to suggest that either the pump location reporting is more accurate in the Tennessee Valley, or simply that fewer irrigators registered their water use in the Wiregrass. In 2015, 22.2% of CPs in the Tennessee Valley were greater than 5 miles from a registered pump and 6.8% of CPs were greater than 10 miles from a registered pump. Similarly, in the Wiregrass 21.2% of CPs in the Wiregrass were greater than 5 miles from a registered pump and 4.2% of CPs were greater than 10 miles. The substantial amount of CPs greater than 5 miles from any registered COU pump suggests that there are irrigators in both the Tennessee Valley and Wiregrass who have not registered their irrigation pumps or diversions with AL-OWR. Further details of the proximity analysis for both regions are presented in Appendix 3.

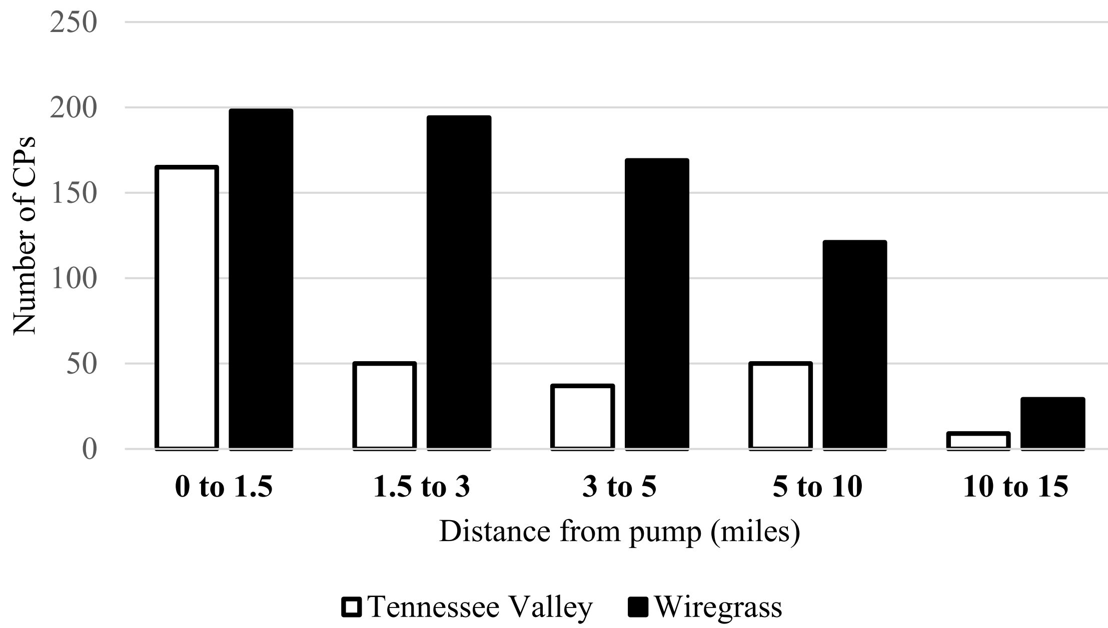

Figure 11: Distance of all CPs in the Tennessee Valley and Wiregrass from the nearest pump in 2015.

Center Pivot Systems Matched with Pumps in the Tennessee Valley

The goal of this project was to match individual COU pumps with CPs, but this was not possible due to issues with pump location accuracy resulting from duplicate registered pump locations. Instead, CPs were matched with their respective COU holder. There were 56, 66, and 74 CPs matched to COU holders across 2011, 2013, and 2015 and accounted for 6,406 acres, 6,992 acres, and 7,438 acres respectively (Figure 12). This suggests that compliance with the program is decreasing as the percent of CPs matched to COU holders out of the total number of CPs decreased from 28.9% (2011), to 25.1% (2013), to 22.8% (2015); however, the uncertainty associated with the inaccurate pump location reporting makes it difficult to be completely confident. Eight COU holders were matched to CP irrigation in 2011 and 2013, and 9 COU holders were matched in 2015.

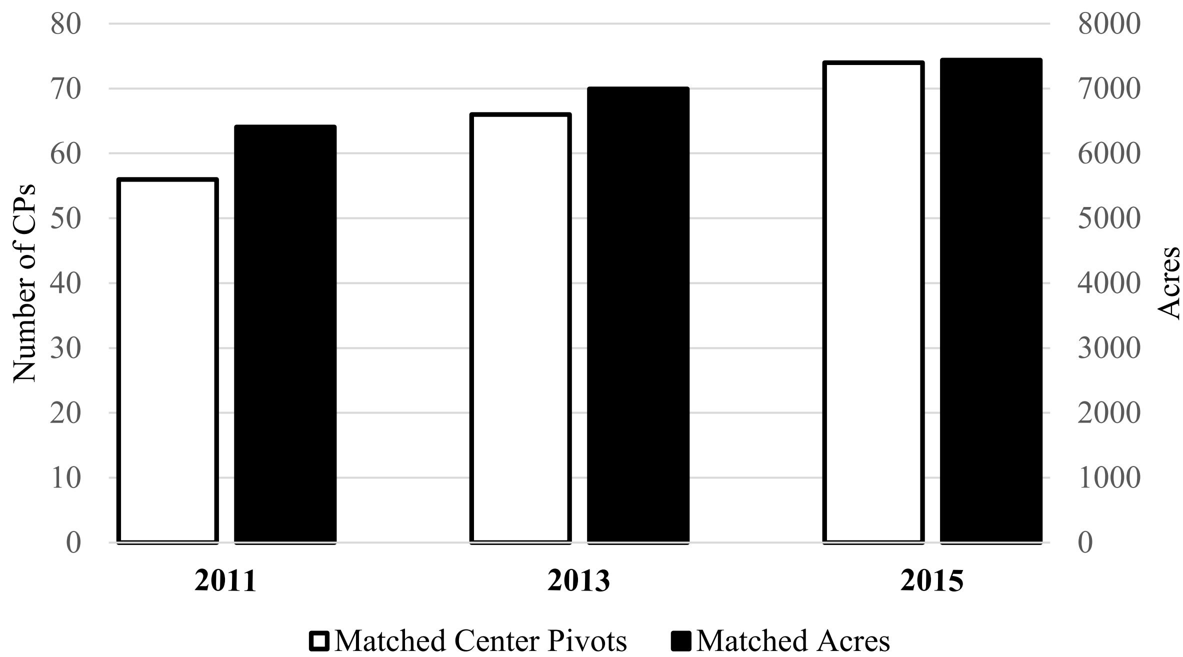

Figure 12: Total number of CPs and associated acres matched to COU holders in the Tennessee Valley.

Comparison of Center Pivot and Pump Matching for the Tennessee Valley and Wiregrass

Compared with the CPs matched to COU holders in the Tennessee Valley for the study years, there were more CPs matched to COU holders in the Wiregrass with 96 CPs matched in 2011 and 116 CPs matched in 2015 (Figure 14). There were more total CPs matched in the Wiregrass than in the Tennessee Valley for all study years, but the percent of CPs matched to a COU holder out of the total number of CPs was higher in the Tennessee Valley than in the Wiregrass for the study period (+8.0% in 2011; +6.6% in 2015) (Figure 15). Additionally, the number of irrigated acres matched to COU holders was higher in the Tennessee Valley than in the Wiregrass (+1,139 acres in 2011; +841 acres in 2015). It is important to note that for comparing the results of matching COUs to CPs for the two regions, the study undertaken by

Barbre (2017) matched CPs to their respective COU based on tax parcel ownership information without consulting the Alabama Secretary of State Business Records. Additionally, the study by Barbre (2017) did not extract the CPs by buffer zones around the pump location. Buffer zones extending 1.5 miles were created around the Wiregrass COU pump locations to extract the CPs identified by Barbre (2017) for the purpose of comparing the results to the Tennessee Valley.

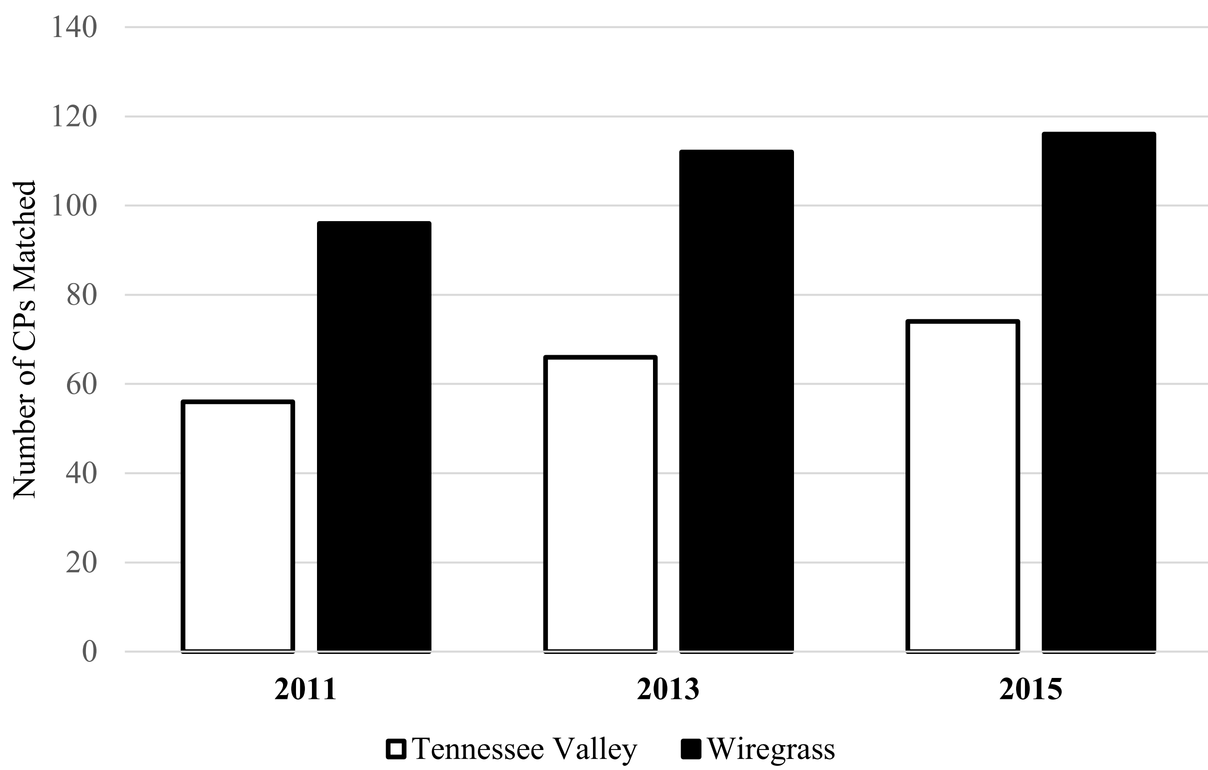

Figure 13: Comparison of total number of CPs matched to COU holders.

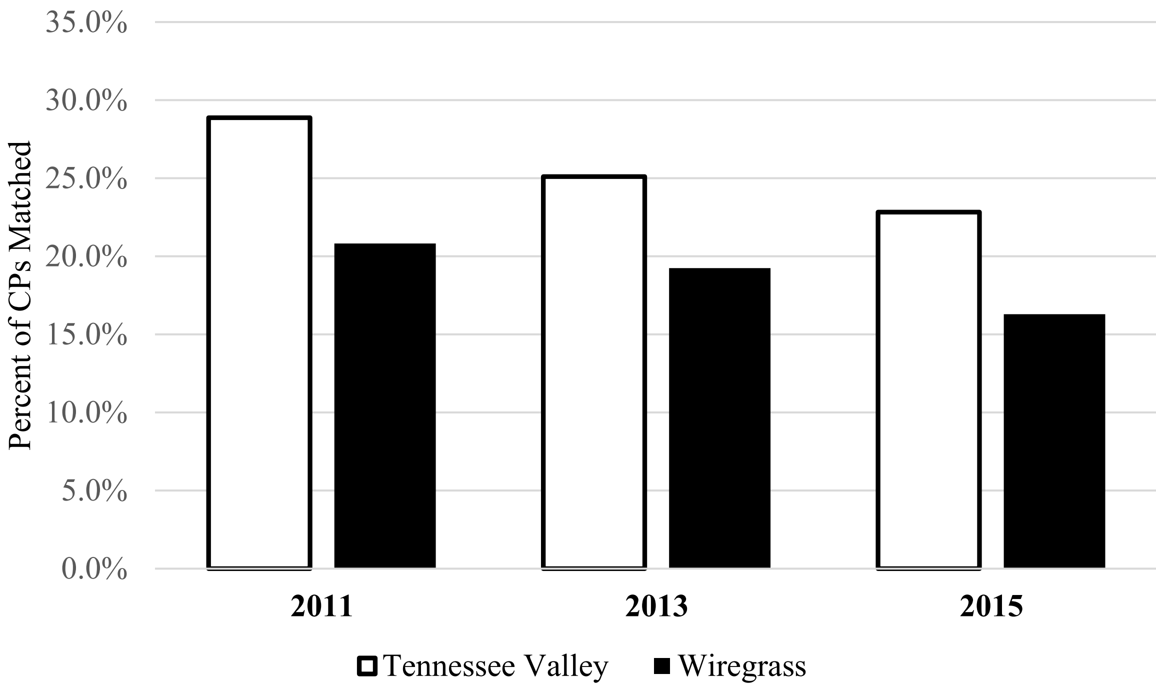

Figure 14: Comparison of percent of CPs matched to COU holders.

Water Use Reporting Compliance for the Tennessee Valley

The percent of annual water use reports submitted out of the total number of registered COUs fluctuated somewhat for the study years, with rates of 63.6% (2011), 74.0% (2013), and 66.2% (2015). The percent of COUs that were reported out of the total number of COUs matched to CPs was 72.1% (2011), 80.3% (2013), and 66.7% (2015). The number of COU holders matched to CPs who were 100% compliant in reporting their annual water use was fairly constant, with one COU holder that was 100% compliant for 2011, and two 100% compliant COU holders in 2013 and again in 2015. The percent of COU holders matched to CPs who were 100% compliant in reporting their annual water use out of the total number of COU holders matched to CPs was 12.5% (2011), 25.0% (2013), and 22.2% (2015). The percentage of 100% compliant COU holders out of all COU holders matched to CPs decreased from 2013 to 2015 because 8 COU holders were matched to CPs in 2013, while 9 COU holders were matched to CPs in 2015.

Comparison of Water Use Reporting in the Tennessee Valley and Wiregrass

The percent of annual water use reports submitted out of the total number of registered COUs was substantially higher in the Tennessee Valley than in the Wiregrass for the study period (+10.4% in 2011; +12.2% in 2015) (Table 6). The percent of annual water use reports submitted out of the total number of registered COUs for the Wiregrass ranged was 53.2% (2011), 51.6% (2013), and 54.0% (2015). The percent of COUs that were reported out of the total number of COUs matched to CPs was also higher (+6.7% in 2011; +3.5% in 2015) in the Tennessee Valley than in the Wiregrass. There were fewer COU holders matched to CPs who were 100% compliant in submitting water use reports in the Tennessee Valley than in the Wiregrass. There were 12 COU holders who were 100% compliant and matched to CP irrigation in the Wiregrass for 2011, 10 in 2013, and 13 in 2015. The percent of 100% compliant COU holders matched to CP irrigation out of the total number of COU holders matched to CP irrigation was also lower in the Tennessee Valley region than in the Wiregrass region for the study years (-42.0% in 2011; -32.0% in 2015).

Overall, the comparison of water use reporting in the two regions suggests compliance issues with the COU reporting program for both regions. The measurement of reporting compliance with the biggest difference between the two regions was the percent of COU holders matched to CP irrigation who were 100% compliant in submitting water use reports. It is likely that the disparity between the two regions for COU holders who were matched to CP irrigation and 100% compliant in submitting water use reports is influenced by the difference in the number of COU holders matched to CP irrigation in each region (8 to 9 COU holders for the Tennessee Valley and 22 to 24 COU holders in the Wiregrass).

Table 6: Compliance indicators for the Tennessee Valley and Wiregrass regions.

	Percent of annual water use reports submitted out of all COUs (%)	Percent of annual water use reports submitted out of all COUs matched to CPs (%)	Percent of COU holders who were matched to CPs and 100% compliant in submitting water use reports for all of their COU (%)
Tennessee Valley			
2011	63.6%	72.1%	12.5%
2013	74.0%	80.3%	25.0%
2015	66.2%	66.7%	22.2%
Wiregrass			
2011	53.2%	63.9%	54.5%
2013	51.6%	67.1%	43.5%
2015	54.0%	62.7%	54.2%

Accuracy Assessment of the Tennessee Valley Water Use Reporting

The average depth of application among COU holders who were matched to CP irrigation and 100% compliant in reporting their water usage (one COU holder in 2011 and 2 COU holders in 2013 and 2015) was 12.93, 12.26, and 66.8 inches for the study years 2011, 2013, and 2015, respectively. Excluding the major outlier of 270.44 inches applied per acre for 1 of the 2 matched and 100% compliant COU holders for 2015 brings the average depth down from 66.8 to 7.96 inches per acre for that year, which is a much more reasonable estimate. The estimated depth of application for CP irrigation in Alabama published by the USDA in the Farm and Ranch Irrigation Survey between 1998 and 2013 was 9.6 inches (1998 and 2003), 7.2 inches (2008), and 4.8 inches (2013) (Glickman and Gonzalez 1999; Veneman and Jen 2004; Vilsack and Clark 2009; Vilsack and Clark 2013). Only one COU holder reporting for a single year (2015) fell within the expected range of 4.8 to 9.6 inches applied per acre estimated by the USDA. Values higher than expected for the Tennessee Valley could be influenced by errors in the water use reporting or simply because the sample population of COU holders in the region was small, but it seems likely that there were errors in creating estimates for areas under CP irrigation due to issues with matching CPs to COU pumps.

Chapter 6: Summary and Conclusions

The purpose of this study was to determine if the problems with Alabama's Certificate of Beneficial Use water use reporting program documented in the Wiregrass region were also present in the Tennessee Valley region. The number of CPs in the region increased by 67%, but no additional pumps were registered during the study period. New pumps were likely installed to support the additional CPs in the region but were not registered with the state, which means that there are irrigators failing to comply with Alabama's COU regulations. The percent of annual water use reports submitted out of the total number of registered COUs varied slightly between 64 to 74%, and percent of COUs that were reported out of the total number of COUs matched to CPs ranged from 66 to 80%. Only between 12 to 25% of COU holders matched to CP irrigation submitted water use reports for all of their COU as required by Alabama law, which was substantially lower than 100% compliance rate among COU holders matched to CP irrigation in the Wiregrass. Assessing the accuracy of the water use reports was complicated by incorrect pump location data, and results were not consistent with the information published by the USDA Farm and Ranch Irrigation Survey. There were six study questions analyzed as a part of the investigation into Alabama's water use reporting program.

1. How many CP sites are in the Tennessee Valley Region of Alabama?

The number of CP sites in the Tennessee Valley increased each year from 194 CPs (20, 341 acres) identified in 2011, 263 CPs (25,998 acres) in 2013, and 324 CPs (30,417 acres) in

2015. Overall, the number of CP sites grew by 67.0% for the entire study period, and the number of irrigated acres increased by 49.5%.

2. How does the change in the number of CP sites in the Tennessee Valley region compare to the Wiregrass region of Alabama?

The number of CP sites identified in the Wiregrass from 2011 to 2015 increased from 461 to 712 (54.4%) (Barbre 2017; Chaney 2017). Compared to the Wiregrass, the Tennessee Valley had less than half as many CP sites identified for each study year, but the number of CP sites documented in the Tennessee Valley grew at a slightly higher rate for the study period (+12.6%).

3. How many CP sites in the Tennessee Valley region can be associated with a COU?

Fifty-six of the 194 CPs identified in 2011, 66 out of 263 CPs in 2013, and 74 CPs out of 324 in 2015 could be matched to a registered COU holder. The percent of CPs matched to a COU holder out of the total number of CPs decreased each year from 28.9% in 2011, 25.1% in 2013, to 22.8% in 2015.

4. How does the number of CP sites with a COU in the Tennessee Valley region compare to the Wiregrass region?

The number of matched CP sites was higher in the Wiregrass than the Tennessee Valley for the study period with 74 and 116 CPs matched to COU holders in 2015 for the Tennessee Valley and Wiregrass respectively, but the percent of CPs matched to a COU holder out of the total number of CPs in the region was consistently higher in the Tennessee Valley than in the

Wiregrass (5.9 to 8.1% higher). Additionally, the percent of CPs matched to a COU holder decreased for each study year in both regions, lowering from 28.9% (2011) to 22.8% (2015) in the Tennessee Valley and 20.8% (2011) to 16.3% (2015) in the Wiregrass. Unfortunately, these results are likely inaccurate due to issues with the pump location reporting. Differences in methodology between this study and the Wiregrass studies further complicates the comparison of the two regions.

5. How does the water use reporting in the Tennessee Valley compare to the Wiregrass?

The percent of annual water use reports submitted out of the total number of registered COUs in the Tennessee Valley region ranged from 63.6% to 74.0%, with no clear pattern observed. The Wiregrass region had lower rates for submitting water use reports ranging from 51.6% to 54.0%. The percent of COU holders matched to CP irrigation who were 100% compliant in submitting water use reports for all of their registered COUs was much lower for the Tennessee Valley than in the Wiregrass, with 12.5% (2011) to 22.2% (2015) who were totally compliant in the Tennessee Valley and 54.5% (2011) to 54.2% (2015) in the Wiregrass.

6. How does the reported volume of water withdrawn for CP irrigation in the Tennessee Valley compare to the water use values estimated by the United States Department of Agriculture's Farm and Ranch Irrigation Survey?

The depths of application for per acre for CP irrigation estimated by the USDA in the Farm and Ranch Irrigation Survey were 9.6 inches (1993 and 2003), 7.2 inches (2008), and 4.8 inches (2013). The calculated average depth applied per acre for COU holders in the Tennessee Valley who submitted all of their registered water use reports was 12.9 inches in 2011, 12.3

inches in 2015, and 66.9 inches in 2015. Removing the major outlier for the 2015 water use reporting lowered the average depth applied to 8.0 inches per acre for 2015. The water use reporting program could not be accurately assessed due to issues with the reported data. Additionally, because only one COU holder in 2011 and two COU holders in 2013 and 2015 reported for all of their registered COUs the results are based on such a small population that they are not reliable.

Recommendations for Alabama's COU Program

Alabama's Certificate of Beneficial Use water use reporting program has the potential to provide valuable information to state and federal agencies, but several issues with the collection of the data make it difficult to determine the accuracy of the information collected. These issues are COU pump location reporting, information on the location and number of irrigation sites supplied by the pump, and the exact method of irrigation being used. AL-OWR needs to revise the COU application forms to correct these problems and educate irrigators on the revisions. Enforcement of the program through penalties for non-compliance would likely improve participation with the program; however, this would require additional staff and funding.

Monitoring the use of water resources is critical for a state to ensure future supplies. Sustainable management requires accurate information on water supply and demand, which is necessary for pro-actively identifying problems. The results of this study will aid state water planners in developing strategies for efficiently managing water resources, and will provide a detailed case study for other state agencies and researchers.

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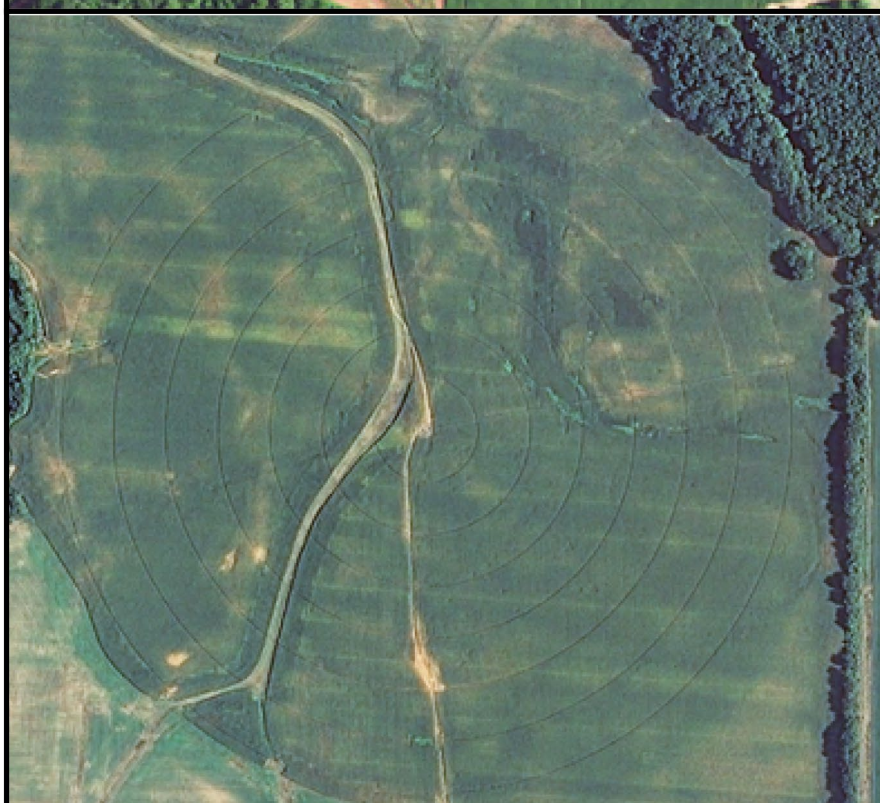
Appendix 1: Center Pivot Identification

A list of identifying CP irrigation characteristics was developed through consulting the visual interpretation methods used by Litts et al. (2001), Millington (2015), and Finkelstein and Nardi (2016). An assessment of the center pivot systems in the Tennessee Valley Region of Alabama was conducted using the NAIP data to expand upon the visual interpretation characteristics identified in the previously mentioned studies. The identifying characteristics are detailed in this appendix.

1.1: Center pivot arm (outlined in red) extending from pivot tower.



1.2: Visible circular wheel tracks in vegetation.

1.3: Distinct vegetation difference between irrigated and unirrigated areas.

1.4 : Visible moisture boundary around irrigated perimeter.

1.5: Access lanes connecting multiple center pivot systems.

1.6: Tailwater pit (outlined in red) for reusing water.

1.7: Possible pivot arm (2011) with unclear landscape characteristics.

1.8: Confirmed pivot arm (2013) with rotation around pivot tower.

Appendix 2: Comparison of Center Pivots in the Tennessee Valley and Wiregrass

This appendix provides a comparison of several metrics between CPs identified within the Tennessee Valley in this study and within the Wiregrass in the studies by Barbre (2017) and Chaney (2017).

2.1: Comparison of Center Pivots for 2011

2.2: Comparison of Center Pivots for 2013

2.3: Comparison of Center Pivots for 2015

Appendix 2.1: Comparison of Center Pivots for 2011

	Tennessee Valley	Wiregrass
Acres Irrigated	20341	23648
CPs	194	461
Average CP Acreage	104.9	51.3
CP Acreage Range	5.8 - 493.2	6.5 - 302.3
CP Acreage Standard Deviation	94.9	38.4
CPs Matched to a CoU	56	96
Matched CP Acres	6406	5522

Appendix 2.2: Comparison of Center Pivots for 2013

	Tennessee Valley	Wiregrass
Acres Irrigated	25998	29350
CPs	263	582
Average CP Acreage	98.9	50.4
CP Acreage Range	5.8 - 508.4	6.2 - 302.3
CP Acreage Standard Deviation	90.9	37.6
CPs Matched to a CoU	66	112
Matched CP Acres	6992	6235

Appendix 2.3: Comparison of Center Pivots for 2015

	Tennessee Valley	Wiregrass
Acres Irrigated	30417	36326
CPs	324	712
Average CP Acreage	93.9	51.0
CP Acreage Range	5.8 - 508.4	3.7 - 312.2
CP Acreage Standard Deviation	86.1	39.5
CPs Matched to a CoU	74	116
Matched CP Acres	7438	6943

Appendix 3: Buffer Analysis of Center Pivots in the Tennessee Valley and Wiregrass

A buffer analysis was conducted using pump locations provided in the COU data by AL-OWR within ArcGIS 10.4.1 to estimate compliance with Alabama's COU program. Buffer zones were created at half-mile intervals around the pump locations, and the number of CPs falling within and outside of each buffer zone was calculated. CP polygons were converted to centroid points to simplify the analysis.

Appendix 3.1: Tennessee Valley Buffer Analysis for 2011

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	50	144	194	25.77%	74.23%
1	95	99	194	48.97%	51.03%
1.5	120	74	194	61.86%	38.14%
2	132	62	194	68.04%	31.96%
2.5	143	51	194	73.71%	26.29%
3	148	46	194	76.29%	23.71%
4	153	41	194	78.87%	21.13%
5	159	35	194	81.96%	18.04%
6	169	25	194	87.11%	12.89%
7	173	21	194	89.18%	10.82%
8	177	17	194	91.24%	8.76%
9	181	13	194	93.30%	6.70%
10	183	11	194	94.33%	5.67%
11	187	7	194	96.39%	3.61%
12	187	7	194	96.39%	3.61%
13	187	7	194	96.39%	3.61%
14	187	7	194	96.39%	3.61%
15	189	5	194	97.42%	2.58%

Appendix 3.2: Tennessee Valley Buffer Analysis for 2013

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	63	200	263	23.95%	76.05%
1	114	149	263	43.35%	56.65%
1.5	147	116	263	55.89%	44.11%
2	164	99	263	62.36%	37.64%
2.5	177	86	263	67.30%	32.70%
3	186	77	263	70.72%	29.28%
4	200	63	263	76.05%	23.95%
5	207	56	263	78.71%	21.29%
6	226	37	263	85.93%	14.07%
7	235	28	263	89.35%	10.65%
8	241	22	263	91.63%	8.37%
9	247	16	263	93.92%	6.08%
10	251	12	263	95.44%	4.56%
11	256	7	263	97.34%	2.66%
12	256	7	263	97.34%	2.66%
13	256	7	263	97.34%	2.66%
14	256	7	263	97.34%	2.66%
15	258	5	263	98.10%	1.90%

Appendix 3.3: Tennessee Valley Buffer Analysis for 2015

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	70	254	324	21.60%	78.40%
1	128	196	324	39.51%	60.49%
1.5	165	159	324	50.93%	49.07%
2	186	138	324	57.41%	42.59%
2.5	205	119	324	63.27%	36.73%
3	215	109	324	66.36%	33.64%
4	234	90	324	72.22%	27.78%
5	252	72	324	77.78%	22.22%
6	271	53	324	83.64%	16.36%
7	281	43	324	86.73%	13.27%
8	289	35	324	89.20%	10.80%
9	297	27	324	91.67%	8.33%
10	302	22	324	93.21%	6.79%
11	307	17	324	94.75%	5.25%
12	308	16	324	95.06%	4.94%
13	309	15	324	95.37%	4.63%
14	309	15	324	95.37%	4.63%
15	311	13	324	95.99%	4.01%

Appendix 3.4: Wiregrass Buffer Analysis for 2011

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	61	400	461	13.23%	86.77%
1	109	352	461	23.64%	76.36%
1.5	152	309	461	32.97%	67.03%
2	197	264	461	42.73%	57.27%
2.5	240	221	461	52.06%	47.94%
3	278	183	461	60.30%	39.70%
4	337	124	461	73.10%	26.90%
5	380	81	461	82.43%	17.57%
6	402	59	461	87.20%	12.80%
7	423	38	461	91.76%	8.24%
8	432	29	461	93.71%	6.29%
9	444	17	461	96.31%	3.69%
10	449	12	461	97.40%	2.60%
11	452	9	461	98.05%	1.95%
12	456	5	461	98.92%	1.08%
13	458	3	461	99.35%	0.65%
14	461	0	461	100.00%	0.00%
15	461	0	461	100.00%	0.00%

Appendix 3.5: Wiregrass Buffer Analysis for 2013

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	69	513	582	11.86%	88.14%
1	126	456	582	21.65%	78.35%
1.5	179	403	582	30.76%	69.24%
2	242	340	582	41.58%	58.42%
2.5	300	282	582	51.55%	48.45%
3	348	234	582	59.79%	40.21%
4	426	156	582	73.20%	26.80%
5	484	98	582	83.16%	16.84%
6	509	73	582	87.46%	12.54%
7	533	49	582	91.58%	8.42%
8	543	39	582	93.30%	6.70%
9	557	25	582	95.70%	4.30%
10	564	18	582	96.91%	3.09%
11	568	14	582	97.59%	2.41%
12	573	9	582	98.45%	1.55%
13	576	6	582	98.97%	1.03%
14	579	3	582	99.48%	0.52%
15	581	1	582	99.83%	0.17%

Appendix 3.6: Wiregrass Buffer Analysis for 2015

Buffer Distance (miles)	Pivots Inside Buffer	Pivots Outside Buffer	Total Pivots	Percent Inside	Percent Outside
0.5	70	642	712	9.83%	90.17%
1	136	576	712	19.10%	80.90%
1.5	198	514	712	27.81%	72.19%
2	274	438	712	38.48%	61.52%
2.5	335	377	712	47.05%	52.95%
3	392	320	712	55.06%	44.94%
4	491	221	712	68.96%	31.04%
5	561	151	712	78.79%	21.21%
6	597	115	712	83.85%	16.15%
7	631	81	712	88.62%	11.38%
8	652	60	712	91.57%	8.43%
9	672	40	712	94.38%	5.62%
10	682	30	712	95.79%	4.21%
11	691	21	712	97.05%	2.95%
12	699	13	712	98.17%	1.83%
13	706	6	712	99.16%	0.84%
14	709	3	712	99.58%	0.42%
15	711	1	712	99.86%	0.14%

Appendix 4: COU Water Use Data Tables

This appendix provides a comparison for water use data reported by COU holders for each study year for the two regions. Only water use data for COU holders that were matched to CP irrigation are included. For privacy purposes, the actual COU number assigned to each COU holder is not disclosed, but an arbitrary owner identification number was assigned instead to distinguish between COU holders. The COU data is categorized by groundwater (GW) COUs, surface water (SW) COUs, and all COUs.

Appendix 4.1: Tennessee Valley COU Holder Tables

Appendix 4.1.1: Tennessee Valley COU Holder Table 2011

Owner ID	#COU Total	#GW COU	#SW COU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
3	3	0	3	3	4	777.34	0.00	273.00	273.00	12.93
5	5	1	4	3	3	303.00	6.92	5.18	12.10	1.47
6	19	17	2	16	26	1887.60	395.84	298.69	694.53	13.55
7	5	2	3	0	5	654.37	0.00	0.00	0.00	0.00
8	2	0	2	0	3	573.80	0.00	0.00	0.00	0.00
11	13	5	8	12	3	224.35	264.00	1488.00	1752.00	287.60
12	4	1	3	2	6	1205.81	71.60	87.41	159.01	4.86
15	10	0	10	8	6	779.83	0.00	406.14	406.14	19.18
Totals	**61**	**26**	**35**	**44**	**56**	**6406.1**	**738.36**	**2558.42**	**3296.78**	**18.95**

Appendix 4.1.2: Tennessee Valley COU Holder Table 2013

Owner ID	#COU Total	#GW COU	#SW COU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
3	3	0	3	3	4	775.50	0.00	16.20	16.20	0.77
5	5	1	4	3	4	401.07	3.46	5.18	8.64	0.79
6	19	17	2	19	31	2057.75	623.65	303.77	927.42	16.60
7	5	2	3	0	5	654.31	0.00	0.00	0.00	0.00
8	2	0	2	0	4	610.65	0.00	0.00	0.00	0.00
11	13	5	8	12	3	224.35	335.50	1485.00	1820.50	298.84
12	4	1	3	4	8	1433.50	1.20	4.20	5.40	0.14
15	10	0	10	8	7	834.41	0.00	336.78	336.78	14.86
Totals	**61**	**26**	**35**	**49**	**66**	**6991.54**	**963.81**	**2151.13**	**3114.94**	**16.41**

Appendix 4.1.3: Tennessee Valley COU Holder Table 2015

Owner ID	#COU Total	#GW COU	#SW COU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
3	3	0	3	3	4	775.65	0.00	167.70	167.70	7.96
5	5	1	4	3	4	401.07	10.37	9.87	20.24	1.86
6	19	17	2	16	31	2059.15	370.57	136.19	506.76	9.06
7	5	2	3	0	5	654.31	0.00	0.00	0.00	0.00
8	2	0	2	0	4	610.65	0.00	0.00	0.00	0.00
11	13	5	8	13	3	224.35	384.50	1263.00	1647.50	270.44
12	4	1	3	0	9	1552.60	0.00	0.00	0.00	0.00
13	5	3	2	0	6	254.87	0.00	0.00	0.00	0.00
15	10	0	10	9	8	905.43	0.00	216.48	216.48	8.81
Totals	**66**	**29**	**37**	**44**	**74**	**7438.08**	**765.44**	**1793.24**	**2558.68**	**12.67**

Appendix 4.2: Wiregrass COU Holder Tables

Appendix 4.2.1: Wiregrass COU Holder Table 2011

Owner ID	#COU Total	#GW COU	#SW COU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
1	13	13	0	11	23	1687.58	897.32	0.00	897.32	19.58
2	1	1	0	1	4	306.37	231.35	0.00	231.35	27.81
5	3	0	3	3	3	312.24	0.00	248.21	248.21	29.28
7	14	4	10	12	8	517.23	116.08	519.23	635.31	45.24
8	3	1	2	0	3	118.43	0.00	0.00	0.00	0.00
11	2	1	1	0	1	41.89	0.00	0.00	0.00	0.00
12	2	0	2	0	5	363.15	0.00	0.00	0.00	0.00
14	1	0	1	1	3	59.46	0.00	35.69	35.69	22.10
15	5	1	4	0	10	290.47	0.00	0.00	0.00	0.00
20	8	7	1	1	6	186.83	10.21	0.00	10.21	2.01

22	5	4	1	5	4	362.63	718.73	0.00	718.73	77.10
26	2	1	1	0	2	182.66	0.00	0.00	0.00	0.00
27	4	2	2	4	3	137.38	54.29	71.33	125.62	33.68
28	5	2	3	5	2	142.21	130.04	180.21	310.25	80.35
36	4	2	2	4	7	307.35	86.73	208.25	294.98	35.35
39	1	0	1	1	1	59.33	132.03	0.00	132.03	81.96
40	1	0	1	1	1	62.38	174.17	0.00	174.17	102.83
41	2	1	1	0	1	108.15	0.00	0.00	0.00	0.00
42	1	0	1	0	3	67.75	0.00	0.00	0.00	0.00
43	1	0	1	1	4	156.41	57.08	0.00	57.08	13.44
44	2	0	2	2	1	26.2	0.00	32.46	32.46	45.63
45	1	0	1	1	1	25.93	0.00	0.00	0.00	0.00
Totals	**81**	**40**	**41**	**53**	**96**	**5522.02**	**2640.48**	**1303.32**	**3943.80**	**26.30**

Appendix 4.2.2: Wiregrass COU Holder Table 2013

Owner ID	#COU Total	#GW CoU	#SW CoU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
1	13	13	0	11	29	1864.96	390.16	0.00	390.16	7.70
2	1	1	0	1	4	321.3	38.00	0.00	38.00	4.36
5	3	0	3	3	3	322.18	0.00	118.07	118.07	13.50
7	14	4	10	14	7	479.04	65.13	262.29	327.42	25.17
8	3	1	2	0	3	134.06	0.00	0.00	0.00	0.00
11	2	1	1	0	1	41.06	0.00	0.00	0.00	0.00
12	2	0	2	0	8	511.82	0.00	0.00	0.00	0.00
14	1	0	1	1	3	56.62	15.47	0	15.47	10.06
15	5	1	4	0	11	320.97	0.00	0.00	0.00	0.00
20	8	7	1	6	8	219.2	0.00	0.00	0.00	0.00
22	5	4	1	5	5	481.94	65.67	0.00	65.67	5.02

26	2	1	1	0	2	182.66	0.00	0.00	0.00	0.00
27	4	2	2	4	5	233.16	38.33	44.70	83.03	13.11
28	5	2	3	5	2	141.39	85.77	170.85	256.62	66.84
29	1	0	1	1	1	62.88	0.00	0.00	0.00	0.00
36	4	2	2	0	7	303.88	0.00	0.00	0.00	0.00
39	1	0	1	0	1	59.33	0.00	0.00	0.00	0.00
40	1	0	1	0	2	105.35	0.00	0.00	0.00	0.00
41	2	1	1	1	1	115.42	0.00	0.00	0.00	0.00
42	1	0	1	0	3	64.45	0.00	0.00	0.00	0.00
43	1	0	1	1	4	161.3	11.47	0.00	11.47	2.62
44	2	0	2	2	1	25.86	10.62	0.00	10.62	15.12
45	1	0	1	0	1	26.12	0.00	0.00	0.00	0.00
Totals	**82**	**40**	**42**	**55**	**112**	**6234.95**	**720.61**	**595.92**	**1316.53**	**7.78**

Appendix 4.2.3: Wiregrass COU Holder Table 2015

Owner ID	#COU Total	#GW COU	#SW COU	#Submitted Water Use Reports	#CPs	Area (acres)	GW Reported Use (million gallons)	SW Reported Use (million gallons)	Total Reported Use (million gallons)	Average Depth Applied (inches/acre)
1	13	13	0	11	27	1965.6	363.19	0.00	363.19	6.80
2	1	1	0	1	4	339.72	64.30	0.00	64.30	6.97
5	3	0	3	3	3	345.05	0.00	252.70	252.70	26.97
7	14	4	10	14	7	540.7	67.62	240.26	307.88	20.97
8	3	1	2	0	3	125.27	0.00	0.00	0.00	0.00
11	2	1	1	0	1	43.18	0.00	0.00	0.00	0.00
12	2	0	2	0	11	586.02	0.00	0.00	0.00	0.00
14	1	0	1	0	3	69.84	0.00	0.00	0.00	0.00
15	5	1	4	0	12	353.38	0.00	0.00	0.00	0.00
17	2	0	2	2	1	74.32	0.00	283.14	283.14	140.31
20	8	7	1	0	9	293.28	0.00	0.00	0.00	0.00

22	5	4	1	5	4	548.51	229.39	0.00	229.39	15.40
26	2	1	1	2	2	203.61	0.52	2.74	3.26	0.59
27	4	2	2	4	5	234.07	42.85	59.95	102.80	16.17
28	5	2	3	4	2	150.35	50.02	172.60	222.62	54.53
29	1	0	1	1	1	82.51	0.00	0.00	0.00	0.00
36	4	2	2	0	7	321.51	0.00	0.00	0.00	0.00
37	1	0	1	1	1	50.54	0.00	534.30	534.30	389.34
39	1	0	1	1	1	66.31	0.00	231.06	231.06	128.33
40	1	0	1	1	2	99.52	0.00	252.60	252.60	93.48
41	2	1	1	0	2	159.49	0.00	0.00	0.00	0.00
42	1	0	1	0	3	67.8	0.00	0.00	0.00	0.00
43	1	0	1	1	4	196.7	0.00	31.85	31.85	5.96
45	1	0	1	1	1	25.78	0.00	12.58	12.58	17.97
Totals	**83**	**40**	**43**	**52**	**116**	**6943.06**	**817.89**	**2073.77**	**2891.66**	**15.34**

Appendix 4.3: Comparison of Water Use Data

Appendix 4.3.1: Comparison for 2011

		Tennessee Valley	Wiregrass
All COU Data	COU Holders	17	45
	Individual COU	77	126
	Percent of Annual Reports Submitted	64.65%	53.17%
	Total Reported Use (million gallons)	3685.62	5599.36
	GW COU	30	54
	GW Reported Use (million gallons)	1014.58	3371.87
	SW COU	47	72
	SW Reported Use (million gallons)	2671.04	2227.49
Matched COU Data	COU Holders Matched to a CP	8	22
	Individual COU Matched to a CP	61	81
	Percent of Annual Reports Submitted for Matched COU	72.13%	65.43%
	Matched COU Total Reported Use (million gallons)	3296.78	3943.80
	GW COU Matched to a CP	26	40
	Matched GW COU Reported Use (million gallons)	738.36	2640.48
	SW COU Matched to a CP	35	41
	Matched SW COU Reported Use (million gallons)	2558.42	1303.32
	Average Depth Applied (inches/acre)	18.95	26.30

Appendix 4.3.2: Comparison for 2013

		Tennessee Valley	Wiregrass
All COU Data	COU Holders	17	45
	Individual COU	77	126
	Percent of Annual Reports Submitted	74.03%	51.59%
	Total Reported Use (million gallons)	3357.96	1591.88
	GW COU	30	54
	GW Reported Use (million gallons)	1007.85	734.38
	SW COU	47	72
	SW Reported Use (million gallons)	2350.11	857.49
Matched COU Data	COU Holders Matched to a CP	8	23
	Individual COU Matched to a CP	61	82
	Percent of Annual Reports Submitted for Matched COU	80.33%	67.07%
	Matched COU Total Reported Use (million gallons)	3114.94	1316.53
	GW COU Matched to a CP	26	40
	Matched GW COU Reported Use (million gallons)	963.81	720.61
	SW COU Matched to a CP	35	42
	Matched SW COU Reported Use (million gallons)	2151.13	595.92
	Average Depth Applied (inches/acre)	16.91	7.78

Appendix 4.3.3: Comparison for 2015

		Tennessee Valley	Wiregrass
All COU Data	COU Holders	17	45
	Individual COU	77	126
	Overall Compliance Rate	66.23%	53.97%
	Total Reported Use (million gallons)	2625.00	4061.94
	GW COU	30	54
	GW Reported Use (million gallons)	765.44	817.89
	SW COU	47	72
	SW Reported Use (million gallons)	1859.13	3244.05
Matched COU Data	COU Holders Matched to a CP	9	24
	Individual COU Matched to a CP	66	83
	Matched COU Compliance Rate	66.67%	62.65%
	Matched COU Total Reported Use (million gallons)	2558.68	2891.66
	GW COU Matched to a CP	29	40
	Matched GW COU Reported Use (million gallons)	765.44	817.89
	SW COU Matched to a CP	37	43
	Matched SW COU Reported Use (million gallons)	1625.54	2073.77
	Average Depth Applied (inches/acre)	13.22	15.34