Irrigation and Certificate of Use Compliance in the Wiregrass Region of Alabama

by

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Abstract

Alabama passed the Water Resources Act of 1993 that included a Certificate of Use (CoU) program for users that have the capacity to withdraw 100,000 gallons per day or more. However, there is concern that some irrigation users do not apply for a CoU for various reasons. The primary focus of this study is on center pivot (CP) irrigation systems used for crop production; but other types of irrigation (e.g., golf courses, turfgrass farms, greenhouses) will also be considered. The objectives of the study are 1) to estimate CoU compliance for irrigation users in each sector and 2) to estimate water use for each agricultural sector from monthly reports provided by the CoU holders. Center pivot irrigation systems were visually identified on NAIP imagery for 2011, 2013, and 2015. Landowner data (owner name, mailing address, and parcel size) were linked to each CP by utilizing the online GIS portals of the counties in the study area. Certificate of Use holder data were then linked to the appropriate CPs for computing the compliance rate. The number of CPs for crop production increased each year: 2011 (425), 2013 (533), and 2015 (638); however, CoU compliance rate decreased each year from 27.5% in 2011 to 24.8% in 2013 to 22.7% in 2015. Approximately 49.1% of CP CoU holders submitted monthly withdrawal reports over the three years being investigated. These data were used to compute the reported amount withdrawn each year, and to estimate the unreported amount and total amount. A major decline in withdrawals in 2013 and increased withdrawals again in 2015 was likely related to variations in precipitation.

Acknowledgements

I first have to acknowledge God whom has given me a passion for geography and the ability to endure these last two years and overcome the obstacles set before me. I would like to thank Dr. Chaney for taking me in, advising me, and investing in me as his student. He went above and beyond by sending me to many conferences so that I could present the research I conducted. It was a joy to be able to write a thesis on a topic that I am passionate about — water resources. As a result of his influence, I am a more well-rounded as a person and professional. I am grateful for the Auburn Geosciences Department for funding my research and graduate school experience.

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Chapter 1: Introduction

The state of Alabama is relatively rich in water resources compared to many other places. Approximately 533 trillion gallons of water are stored in Alabama's aquifers and 33.5 trillion gallons flow through Alabama's streams each year (Mattee, O'Neil, Pierson 1996). Furthermore, the amount of water that flows through Alabama accounts for 15 percent of all surface flow in the contiguous United States (Water Information 2016). However, the state still needs to be diligent in monitoring how that water is used to ensure an adequate supply for present and future demands. Irrigation for agricultural production and related economic activities is an important use of that water in Alabama. For example, a recent study found that 12 percent of water withdrawals in Alabama in 2010 were used for irrigation (Harper and Turner 2015). The state passed the Water Resources Act of 1993 establishing a variety of water monitoring regulations including a Certificate of Use (CoU) program for water users that have the capacity to withdraw 100,000 gallons per day (GPD) or more. However, there is concern that some irrigation users do not apply for a CoU because they are unaware of the program, forget to apply, or choose not to participate.

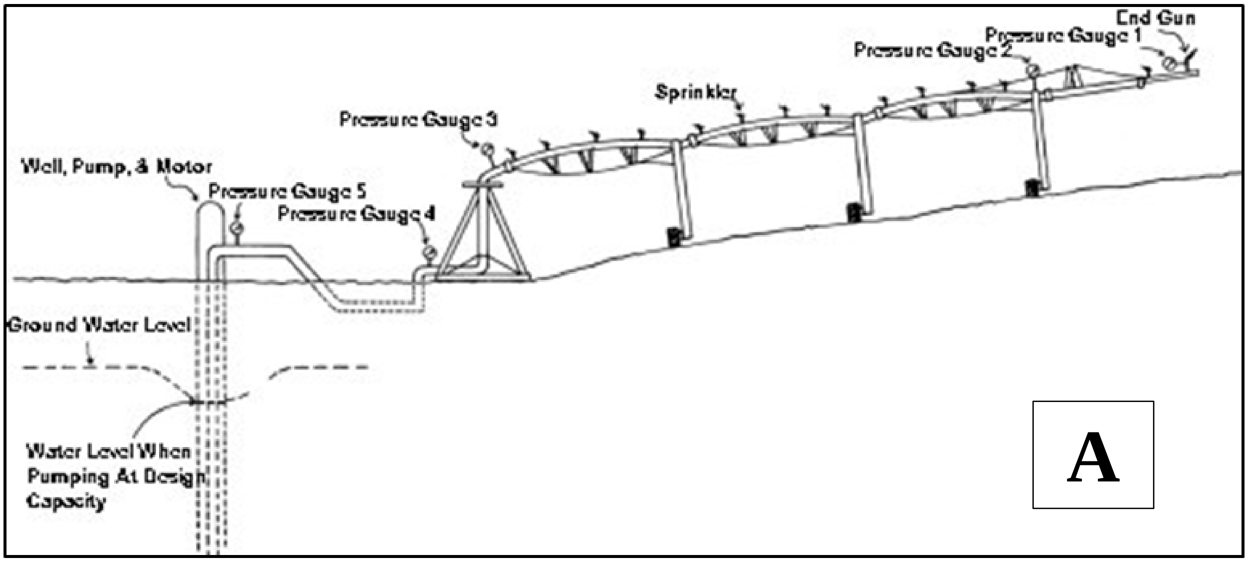
Many states require permits for irrigation users varying in withdrawal amounts (e.g., 10,000 GPD, 25,000 GPD, 100,000 GPD). The enforcement and verification methods by which states monitor permit compliance can be grouped into four categories: 1) little or no enforcement, 2) field checks, 3) citizen complaint, and 4) Geographic Information Systems (GIS) with Remote Sensing (RS) (see section 2.3 and Appendix 1 for further details). Geographic

Information System and RS technologies are valuable tools for detecting the distinct circular pattern created by center pivot irrigation systems (Figure 1 and 2) and for distinguishing between irrigated and non-irrigated crops in regions with drier climate conditions. States that currently rely on GIS/RS to monitor permit compliance include Minnesota, Georgia, Nebraska, and Idaho.

1.1 Research Questions

In Alabama, Handyside (2014) used GIS and RS technology to conduct an inventory of center pivot irrigation systems for selected counties from 2006 to 2011, and followed up with a statewide inventory in 2013. However, the percent of center pivot irrigation systems with a CoU has not been investigated to date. Although some CoU holders provide monthly reports of water withdrawals, there is concern about the total amount of water used for irrigation in the state. The study area for this project is the Wiregrass Region of Alabama. The primary research questions for this project are as follows:

1. How many center pivot irrigation systems are there in the study area?
2. How many center pivot irrigation systems have a certificate of use?
3. What is the total volume of water withdrawn by center pivot irrigators in the study area?
4. How many other irrigators (e.g., golf courses, turfgrass farms, greenhouse/nurseries) are there in the study area, how many have a CoU, and what is the total volume of water withdrawn by those additional irrigators?



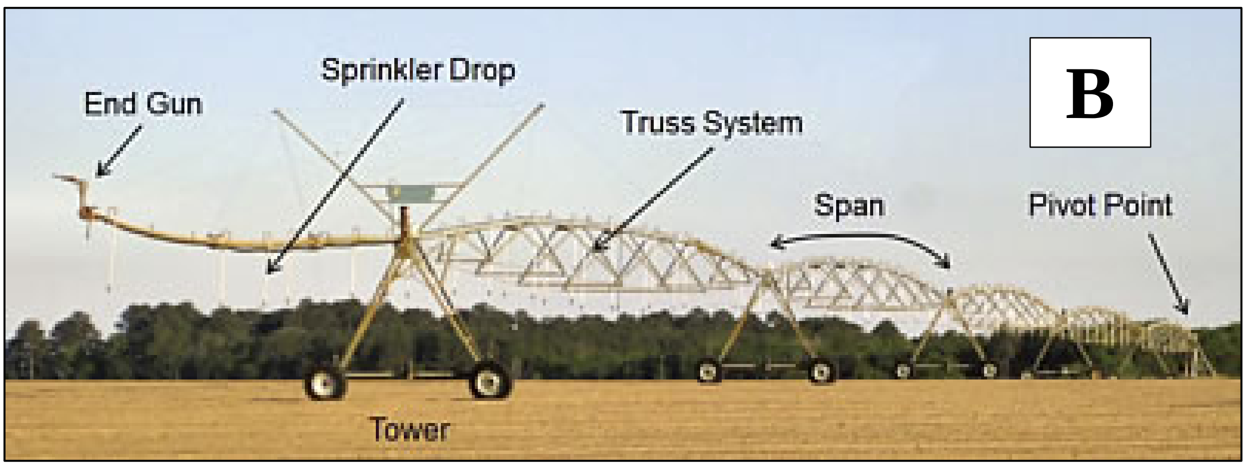


Figure 1. Examples of center pivot irrigation systems: A) illustration from *Curtis and Tyson (1988)*, B) photo with components labeled from *Irrigation System Overview*.

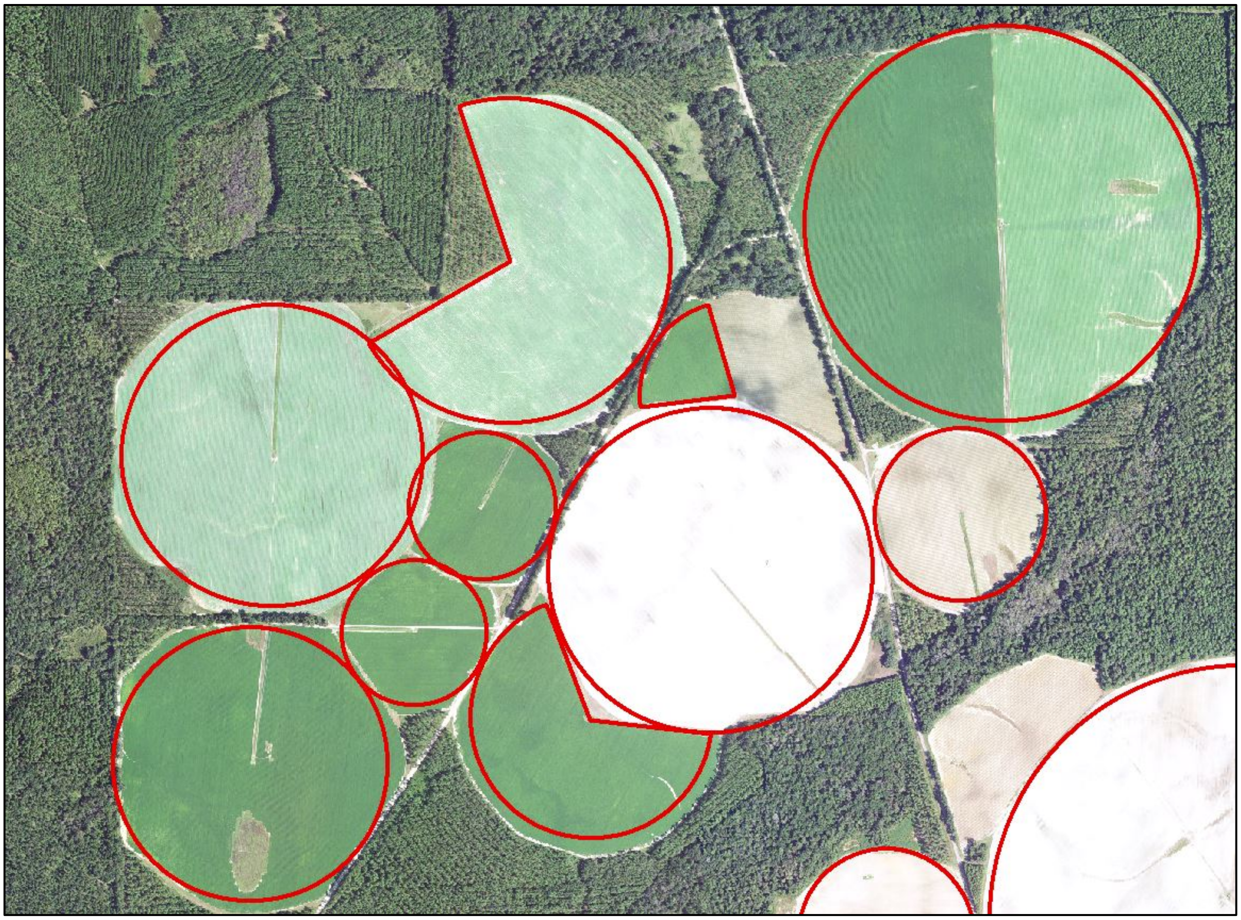


Figure 2. Circular pattern of center pivot irrigation systems

Chapter 2: Literature Review

2.1 A Need for Water Management

The 1900s have been called the golden age of water due to water being cheap, safe, and abundant (Fishman 2012). During that time the population of the world increased by a factor of four and water demand increased by a factor of seven (Human Development Report 2006); however, the amount of water has not changed.

The United States has reached a point where we can no longer rely solely on engineering to solve water supply problems (Reisner 1993). Several major factors contributing to this are after about 1980 all the sites with geotechnical characteristics conducive to dam building had been used (Graf 2001), and the negative environmental impacts of dams on the hydrological continuum are just now being realized. Those environmental impacts include the fragmentation of free-flowing rivers; altered chemical characteristics of the water; sediment being blocked, preventing it from going downstream; decreased water quality; interruption of fish migration patterns; and channelization (Graf 2001, Leopold 1990, Gleick 2003, Wohl et al 2005). Peter Gleick of the Pacific Institute coined the concept of a “soft path” approach to water management which strives to improve the overall productivity of water use rather than seek endless sources of new supply (Gleick 2003). Leopold (1990) echoes Gleick, arguing that decisions in the field of water development and management should aim toward the preservation of the integrity of the hydrological continuum. In other words, water managers need to use water sustainably and not over-allocate surface waters or treat aquifers like a limitless credit card. To manage water in a sustainable way, water managers must advocate for better accountability for the purposes water supplies are put and how much water is used for that purpose. Due to each watershed (i.e., the land area that drains water to a particular stream, river, or lake) having a certain amount of renewable water that is replenished each year, that amount of renewable water should be the basis for the amount of water that is allowed to be withdrawn from the basin (Gleick and Palaniappan 2010).

The need for water management should start with the sector that uses the most water — irrigated agriculture. Worldwide, irrigation accounted for 69 percent of water withdrawals in 2007 (Water Withdrawal 2014), though some researchers put irrigated agriculture as being responsible for up to 85 percent of the world's consumptive water use (Gleick 2003). In the United States during 2010, specifically, irrigation withdrawals account for 61 percent of national water withdrawals (Maupin et al. 2014). The tradeoff is that globally 20 percent of cultivated lands are irrigated yet account for 40 percent of the food produced, and in the United States 17 percent of cultivated lands are irrigated accounting for 50 percent of the nation's crop revenues (Dowgert and Fresno 2010).

2.2 Agricultural Irrigation Water Users

The United States Geological Survey (USGS) defines irrigation as "the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall" (Perlman 2016). These practices include water that is used for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, and dust suppression, as well as leaching salts from the root zone (Maupin et al. 2010). Using this definition, traditional crop cultivators classified as irrigation users, as well as golf courses, turfgrass farms, and greenhouses/nurseries. All branches of the commercial irrigation industry should be accounted for in each region in order to get an accurate depiction of the volume of water the irrigation sector is consuming.

2.2.1 Center Pivot Irrigation Systems

Irrigation of agricultural fields to grow traditional crops is the most common use of irrigation water. There are several methods used to irrigate agriculture crops such as 1) surface irrigation, where water is distributed by gravity over the surface of a field, 2) drip irrigation, which delivers water directly to the individual plant, and 3) sprinkler irrigation, which applies water to the soil using a pressurized piping system with nozzles that spray water into the air (Burt 2000). Sprinkler irrigation is the main technique used by farmers in Alabama in the form of center pivot irrigation systems. A study conducted by Handyside (2014) found that 1,235 center pivot irrigation systems were operational in the state during the 2013 growing season. Combined, these center pivot systems irrigated over 119,000 acres of land.

The amount of water dispersed by center pivot systems depends on each system's capacity and the amount of water each crop needed. System capacity is expressed in terms of either the total flow rate in gallons per minute (GPM) or the application rate in GPM per acre (New and Fipps 2000). The needed flow rate in GPM can be calculated by the formula $Q = (453 \times A \times D)/(F \times H)$. In the formula, Q is the required system flow rate, A is the number of acres, D is the desired depth of water to be placed on the field, F is irrigation frequency, and H is the number of daily hours the system operates (Harrison, Porter, and Perry 2015). The most common operation is to apply a half-inch to an inch of water with a one-and-a-half- to three-day rotation cycle (Burt 2000). For a volume reference, the volume of water required to cover one acre of land in one inch of water is 27,156 gallons. Crop water requirements vary by types and climate. Some commonly used values for consumptive use of crops include: cotton 25 to 35 inches of water, corn 25 to 30 inches of water, and soybeans 20 to 25 inches of water. Water must be put back into the soil at the same rate at which it was withdrawn to maintain the soil-moisture supply (PB1721-Irrigation Cost Analysis Handbook), also affecting the volume of water that needs to be dispersed by the center pivot systems.

2.2.2 Golf Courses

Golf courses are another major commercial user of irrigation water. In 2012 the United States Golf Association published a survey of 2,548 courses, accounting for 15 percent of all golf courses across the country. They found that there were 1,504,210 acres of maintained greens, tees, fairways, and roughs. Of the maintained grass, around 80 percent, or 1,198,381 acres, were irrigated. Average water use by region varied from 9.4 inches a year in the New England region to an astounding 47.9 inches in the Southwest (Lyman 2012). During the 1991 – 1992 season, golf courses in Florida irrigated 131,300 acres of land. The courses used an average of 345 million GPD to irrigate those acres (Haydu, Blokland, and Bell 1994). Water use, as reported by the Georgia Golf Course Superintendents Association best management practices report for 2010, shows that an average of 14.06 inches of irrigation water per acre is used during an average rainfall year and up to 30 inches per acre in a dry year (Lewis 2010). The growing season used for the report was April 1 through October 31.

2.2.3 Turfgrass Farms

Like golf courses, turfgrass farms (also known as sod farms) consume a significant amount of water for irrigation purposes. Turfgrass water consumption is a function of plant growth characteristics and environmental conditions. Warm-season turfgrasses can have relatively low water use, with their maximum water use ranging from less than 6mm to 10mm a day. American Buffalo grass and Bermuda grass are exceptionally low water users, being in the

6mm to 7 mm range. Cool-season turfgrasses, like the Fescues, use 7mm to over 10mm of water daily (Huang 2008). In Florida during the 1991 – 1992 growing year, turfgrass farms comprised 46,100 acres and used 37 million gallons of water a day (Haydu, Blokland, and Bell 1994). This equates to 802.6 gallons of water per acre per day. One study found that sod farms in Rhode Island during the summer of 2008 irrigated 1,996 acres of land and used 0.1 inches of water a day through the growing season of May through October (Levin and Zarriello 2013). It should be noted that over 22 inches of rain fell during that time. Nationally, most turgrass farms are irrigated and one study found that all turfgrass farms in Alabama during the 1992 year used irrigation (Perez et al. 1995).

2.2.4 Greenhouses and Nurseries

Perhaps the most often overlooked irrigation users are nurseries and greenhouses. A general rule of thumb used by irrigation designers for nurseries suggests that a minimum of one acre-inch of water capacity is required per acre of nursery stock per day of irrigation (Robins and Klingaman 2010). Although greenhouses may contain smaller plants that use less water, the increased temperatures inside of the greenhouse lead to a higher evapotranspiration rate. A plant inside of a greenhouse would require more water than the same plant outside of the greenhouse. A guideline some managers go by is a requirement for one to two quarts per square foot of growing area per day. One acre of growing space would require approximately 11,000 to 22,000 GPD (Robbins and Klingaman 2010). Tree seedlings are 80 to 90 percent water by weight so it is vital that greenhouse managers give the seedlings enough water (Dumroese, Luna, and Thomas 2009).

A study of irrigation use at container nurseries (i.e., nurseries that grow their plants in above-ground containers) found that the average irrigation volumes applied varied widely from nursery to nursery. The average irrigation use by each nursery, monitored during 1 hour periods, ranged from 0.3 inches to 1.3 inches. The overall average irrigation (minus the location using 1.3 inches) was 0.6 inches per hour per acre (Fare, Gilliam, and Keever 1992). A study of Alabama nurseries used growers who watered one hour daily (Fain et al. 1999). Over two years 24 nurseries, 838 acres in total, were monitored, concluding that an average of 0.6 inches per acre was applied per one hour watering cycle. If growers used 0.6 inches of water on average across the 838 acres, that would result in over 13.6 million gallons of water being used per hour.

2.3 Methods for Detecting Irrigation Withdrawals Utilized by Various States

Requirements for obtaining some type of permit to withdraw water varies greatly from state to state, with some states such as West Virginia not requiring any documentation. Many states require a water right, CoU, or permit to determine the amount the user is allowed to withdraw, ranging anywhere from 10,000 GPD to 300,000 GPD. Furthermore, some states use the legal doctrine of prior appropriation which is common in the western United States. A survey was conducted to investigate the methods each state's water withdrawal regulating agency employs to determine who is complying with the irrigation regulations set forth. A total of 34 states were contacted with 27 replying via email or phone conversation. The survey concluded that states use a variety of approaches to monitor their programs, including: 1) little or no enforcement, 2) citizen complaints that result in a field check, 3) field checks, 4) field checks and citizen complaints, 5) GIS/ RS and citizen complaints, and 6) a combination of GIS/ RS, field checks, and citizen complaints (for more detailed information see Appendix 1). Figure 3 spatially displays the methods used by states. Georgia and Minnesota look for center pivot systems exclusively, utilizing Google Earth and other high resolution, remotely sensed images to compare with known permit holder records (Ward, Chris. Environmental Specialist, Georgia

Department of Natural Resources. March 2, 2016. Telephone Conversation.; and Hovey, Tom. Water Regulation Unit Supervisor, Division of Ecological and Water Resources, Minnesota Department of Natural Resources. February 22, 2016. Email Correspondence). Precipitation levels in both states make it difficult to distinguish between rain-fed and irrigated crops, thus searching for the center pivot systems was an effective method for monitoring irrigation. An irrigation district in Minnesota used this methodology to determine that 960 of approximately 1000 center pivot irrigation systems had permits, which the district then used to reach 100% compliance (Hovey, Tom. Water Regulation Unit Supervisor, Division of Ecological and Water Resources, Minnesota Department of Natural Resources. February 22, 2016. Email Correspondence). Nebraska also uses this methodology to maintain a near 100 percent compliance rate among crop irrigators (Bradley, Jesse. Programs Director Nebraska Department of Natural Resources. February 23, 2016. Telephone Conversation)

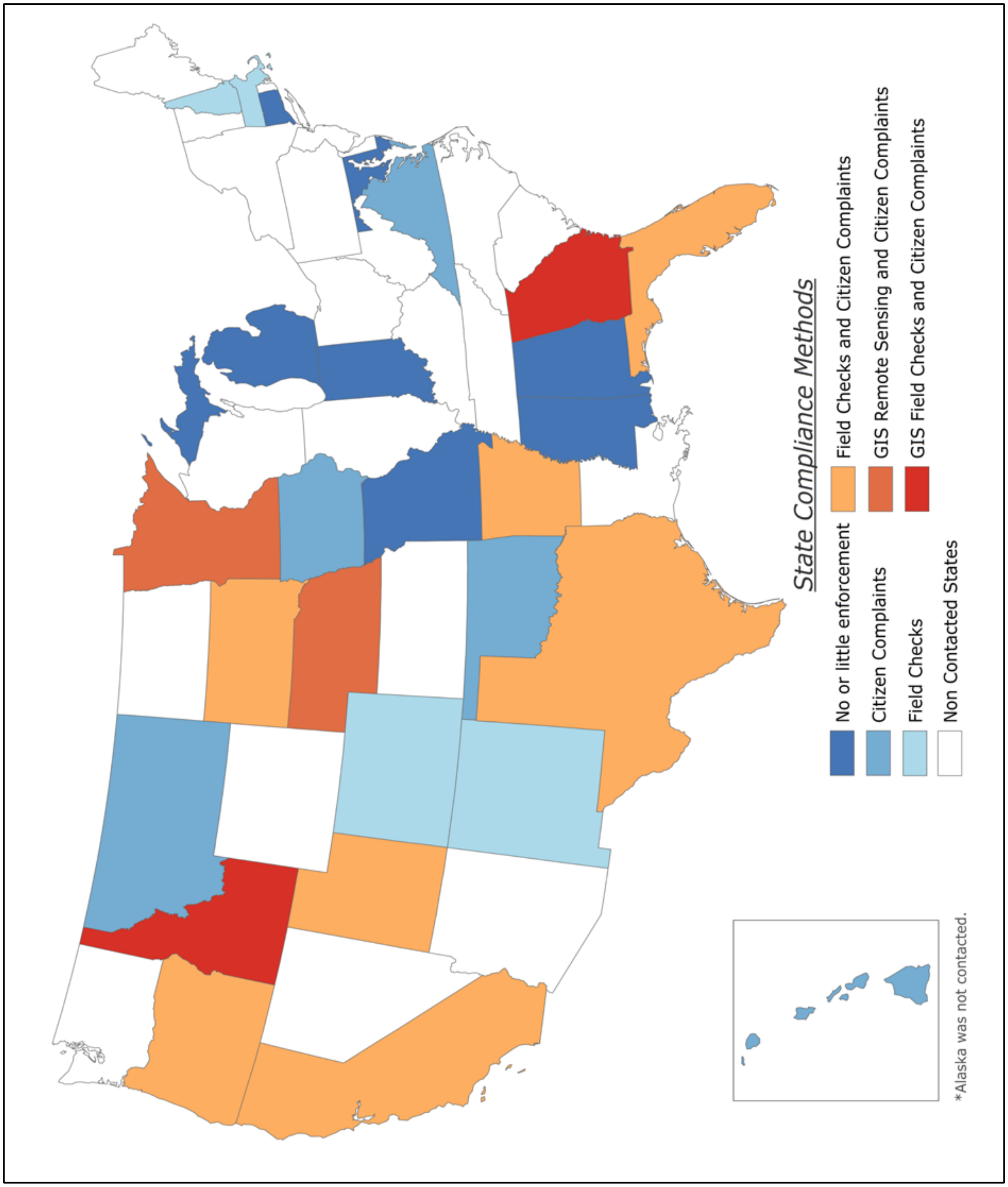


Figure 3. Methods used to monitor compliance with irrigation regulations.

2.4 Remote Sensing Methods for Detecting Irrigation Use

The definition of remote sensing may vary from person to person as “the science and art of obtaining information about an object, area, or phenomenon through the analysis of data that is acquired by a device that is not in contact with the object, area or phenomenon under investigation” (Lillesand, Kiefer, and Chipman 2008) or “the science of acquiring, processing, and interpreting images, and related data, obtained from aircraft and satellites that record the interactions between matter and electromagnetic radiation” (Sabins 1997). In most definitions, a consistent theme of data acquired by sensors not in direct contact with the object or study location prevails. Many studies using RS have been undertaken in an effort to determine irrigation users across the world. The primary methods that have been used in these studies are visual interpretation and digital image classification techniques. More experimental methods, such as object-based image segmentation and evapotranspiration-based extraction, were used in other studies in an attempt to discover better and additional ways of finding irrigated lands. As noted by Ozdogan et al. (2010), the methods used vary from region to region as the climate of an area, the scale of the study, and the timing of the data all limit the techniques that can be successfully used in a region. Table 1 displays the pros and cons of each of the three most popular detection methods.

The most accurate method of determining lands that are irrigated over all land types is by visual interpretation (Ozdogan et al. 2010). Visual interpretation relies on an analyst to visually examine an image, extracting what they interpret as irrigated land. A common theme among irrigation mapping utilizing the visual interpretation method is the use of LANDSAT data, due to it being cheap and covering large areas. The choice in band combination for studies taking the visual interpretation approach have typically been a false color composite (Draeger 1976, Keene and Conley 1980), a false color composite in addition to aerial imagery (Thelin and Heimes 1987, Wall et al. 1977), or a 15-meter panchromatic scheme (Bauder et al. 2004). The study by Bauder et al. (2004) extracted irrigated acreage strictly on the basis of looking for circles in the landscape created by CPs. The basis of the studies using the false color composite was to assume that bright red areas, representing healthy vegetation, were irrigated. Care needs to be taken not to include riparian vegetation that also gives a healthy spectral signature. This method may work in the arid summer-time environments of the West, but it can be problematic in areas that receive high amounts of precipitation. A way that this risk can be reduced is by incorporating multitemporal images throughout the growing season when doing a visual interpretation that is looking for any type of irrigation and not specifically CPs (Draeger 1976, Thelin and Heimes 1987, Wall et al. 1977). The downside of using the visual interpretation method is that it is time consuming meaning costly and, depending on the scale used to extract the irrigated land, acreage calculations could be wrong.

Image classification methods seek to automate the extraction of irrigated lands. By automating the process, extraction time spent by analyst is decreased, making the process more efficient, and, in turn, making digital image classification a cheaper method of extracting irrigation. The overwhelming majority of studies mapping irrigation in this method used the Normalized Difference Vegetation Index (NDVI) method to differentiate between irrigated and rain fed crops (Lenney et al. 1996, Abuzer, McAllister, and Morris 2001, Beltran and Belmonte 2001, Toomanian, Gieske, Akbary 2004, Thenkabail, Schull, Turral 2005). NDVI is derived from the band equation (NIR-Red)/(NIR+Red), resulting in a range of values from -1 to 1. Vegetation values on an NDVI scale range from a low of 0.05 to a high of 0.66+ (Lillesand, Kiefer, and Chipman 2008), with higher values associated with the plant being healthier.

LANDSAT data was the main imagery used throughout the referenced cases, but MODIS and AVHRR are common when mapping large scale irrigation. The greenness index GI=ρNIR/ρGREEN using MODIS data was proven more successful than NDVI because NDVI, at times and in certain areas, cannot distinguish between rain-fed and irrigated crops (Ozdogan & Gutman 2008).

In humid climates, irrigation often takes the form of a supplemental water supply to meet the excess demand of crops whose growth cycle is out of sync with natural precipitation (Ozdogan et al. 2010). Because irrigation in humid climates is typically done to provide a supplemental water supply to the plants, it is commonplace for irrigation studies utilizing image classification indices to perform their classification over several time frames throughout the season to be more accurate. Some studies do a time series of images across the growing season (Toomanian, Gieske, Akbary 2004), two images across two seasons (Abuzar, McAllister, and Morris 2001), a two-year time frame (Thenkabail, Schull, Turral 2005, Thenkabail et al. 2009, Beltran and Belmonte 2001), and even several images over many years (Lenney et al. 1996). Although the setting for the study by Beltran and Belmonte (2001) was in semi-arid Spain, Beltran and Belmonte achieved a classification accuracy of 93.1 percent one year and 90.21 percent the next by using NDVI over multitemporal imagery.

Advances in RS technology have enabled the exploration into experimental approaches to determining instances of irrigated agriculture via object-based extraction (Berberoglu et al. 2000, Walter 2003). Object-based image classification works by classifying groups of pixels with similar characteristics. By using this method, interpretation is based on whole object structures, not just single pixels, and groups can have predefined classes that are automatically assigned based on the parameters of each class (Walter 2003). Berberoglu et al. (2000) was successfully able to classify eight different categories of crops based on their spectral signatures across six bands and the pixel group's texture. It could be possible in some areas that object-based image classification parameters associated with irrigation could be used to find irrigated agriculture. Additionally, temperature and evapotranspiration-rate-based extraction have shown to be potential methods that could be used to distinguish irrigated lands (Bockhold et al.2011, Shakya 2015). The study conducted by Bockhold et al. (2011) was aimed at determining irrigation scheduling based on canopy temperature that was determined by infrared thermometers. While irrigation scheduling was the main focus, what could be concluded from the study is that cooler canopy temperatures are related to recently irrigated crops. Temperature-based extraction may not be a very promising method for finding irrigated lands in the future, but an evapotranspiration-based method appears more promising. A correlation between evapotranspiration amounts and irrigated lands in southeast Alabama has been explored, leading to the conclusion that irrigated lands tend to correlate with higher evapotranspiration rates (Shakya 2015).

Table 1. Strengths and weaknesses of common remote sensing methods in identifying irrigated agriculture. Source: Ozdogan (2010).

Method	**Strengths**	**Weaknesses**
Visual Interpretation	Human analyst thus is extremely accurate	Time consuming and expensive
Digital Image Classification	Cheaper and faster than visual interpretation	In humid regions classifications can become inaccurate
Object-Oriented Classification	Quick, cheap, and considers object shape	In humid regions classifications can become inaccurate and multiple shape identification algorithms may be needed

Chapter 3: Alabama Wiregrass Study Site

The Wiregrass Region covers the coastal plain of southwest Georgia, the southeast corner of Alabama, and the northwest panhandle of Florida (McGregory 1997). The region gets its name from the wiregrass vegetation that thrived in the longleaf pine forests that once dominated the area. Irrigated agriculture has replaced portions of the longleaf pine forests with farmers primarily growing the traditional row crops of peanuts and cotton (National Agriculture Statistics Service 2015). There is no clear cut definition of the extent of the Wiregrass Region into Alabama, but for the purpose of this study, the Wiregrass Region of Alabama is defined as the five most southeastern counties of the state (i.e., Coffee, Dale, Geneva, Henry, and Houston counties) (Figure 4). This area was selected for the project because of the large number of center pivot irrigation systems found in the region in the Handyside (2014) study (483 CPs).

The five counties of the Wiregrass Region cover a total of 1,922,794 acres. Approximately 7.2% of the region is urban or developed (Dothan, Enterprise, Ozark, Geneva, and Headland), 41.4% forest, 9.4% pasture, 18.4% crop land, and 23.6% is used for other purposes (Table 2 and Figure 5). Additionally, Fort Rucker military base covers 3.2% of the study area.

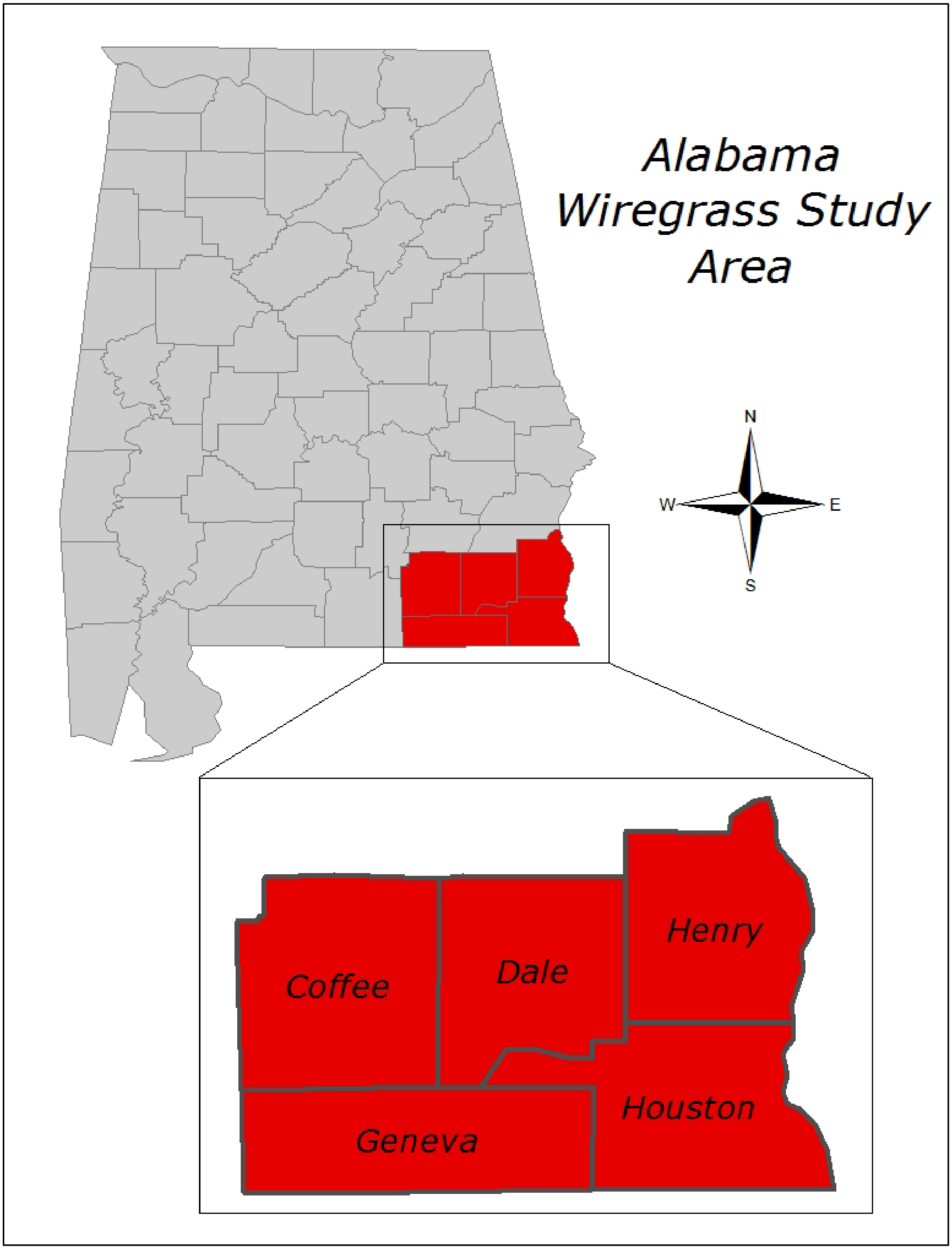


Figure 4. The Wiregrass study area.

Table 2. 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 (2016).

County	Area (Acres)	Percent (%) land cover by county					**Total**
		Urban/ Developed	Forest	Cultivated Crops	Hay/Pasture	Other	
Coffee	357,072.0	6.8	50.4	11.9	9.2	21.7	100.0
Dale	428,962.2	7.7	50.5	11.4	6.8	23.6	100.0
Geneva	361,495.7	5.9	32.9	22.0	14.3	24.9	100.0
Henry	395,792.2	5.1	45.2	17.7	7.1	24.9	100.0
Houston	378,470.8	10.7	27.9	29.0	9.7	22.7	100.0
Wiregrass Region	1,921,792.9	7.2	41.4	18.4	9.4	23.6	100.0

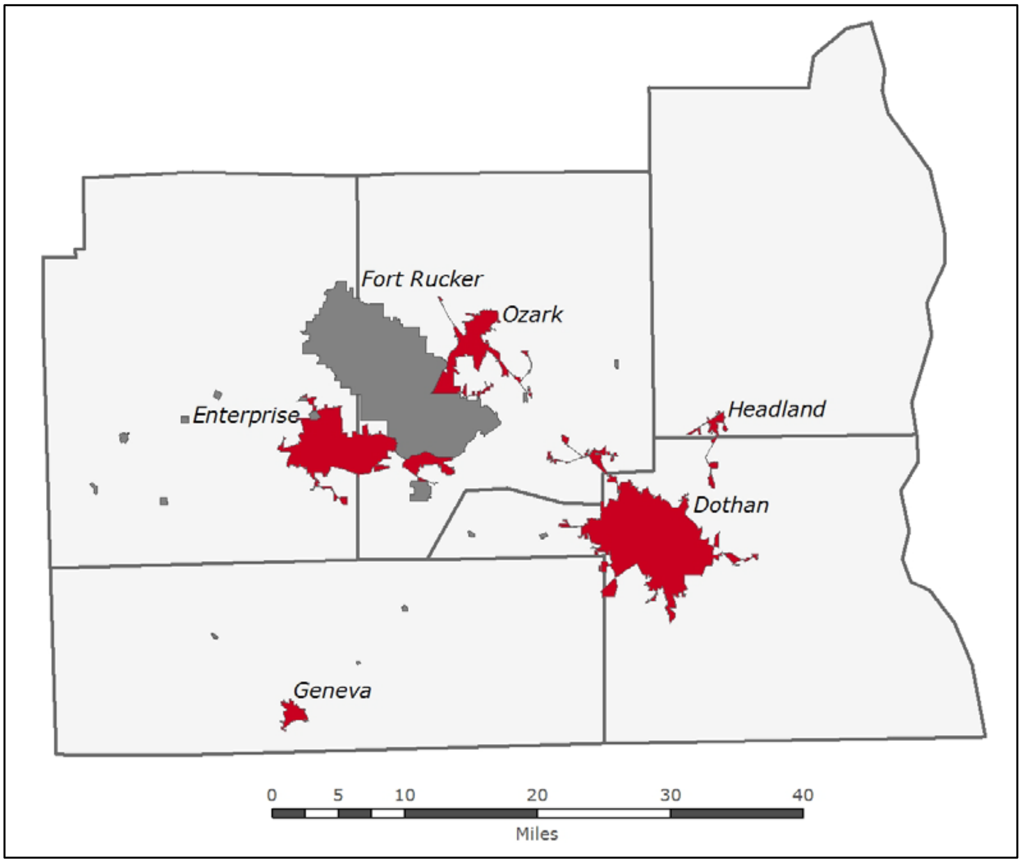


Figure 5. Urban areas and Fort Rucker military base.

Chapter 4: Methods

An investigation of CoU compliance and water use by CPs for crop production and by additional irrigation users was conducted using the GIS software, ESRI ArcGIS 10.3. Certificate of Use holder information and reported-use data for all irrigation users was supplied by the Alabama Office of Water Resources (OWR). A methodology flow chart depicting the major steps used to answer the researh questions investigated in this study is provided in Figure 6.

4.1: Center Pivot Irrigation Systems

4.1.1: Identification of Center Pivot Irrigation Systems

This study used a visual interpretation method similar to that employed by Georgia and Minnesota. National Agricultural Imagery Program (NAIP) data with one-meter resolution was used as in the study by Handyside (2014). The high-resolution NAIP imagery clearly depicted the circular shape of the CPs making them easy to identify for this study. A grid of 1x1-mile cells was created and placed over the five-county study area for a total of 3,163 cells. Each grid cell was visually examined for CPs at a scale of 1:6,000, except when a closer inspection was warranted. When a system was detected, a circular polygon was created with the center point on the irrigation system's pivot point and the radius stretching to the irrigation gun at the end of the system (Figure 7A). For systems that did not cover a full 360 degrees, the polygon was adjusted accordingly to account for the appropriate area irrigated (Figure 7B).

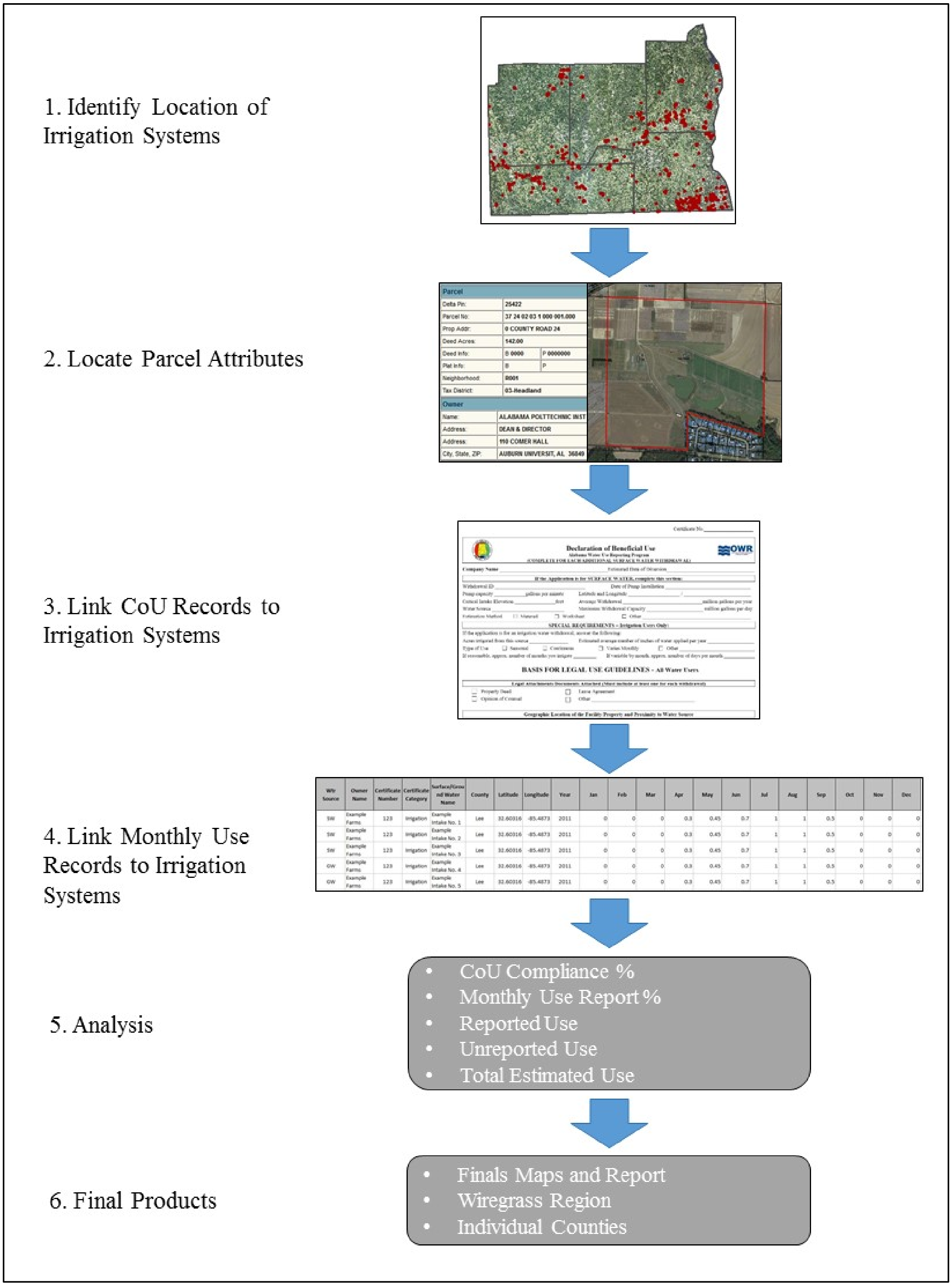


Figure 6. Methodology flow chart.

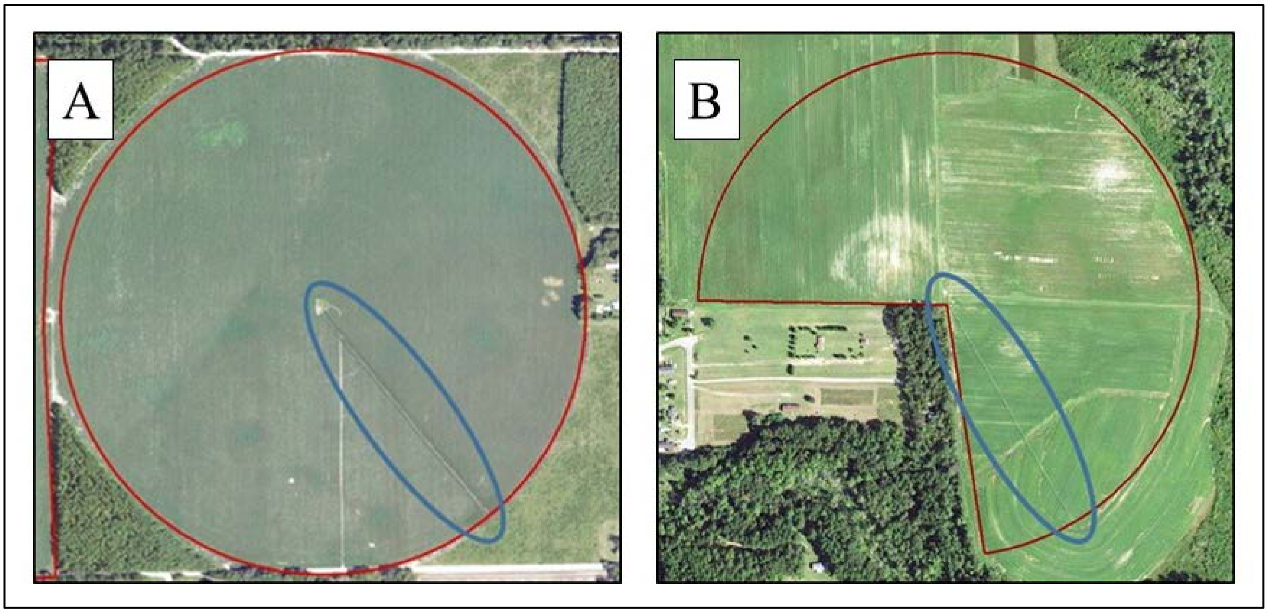


Figure 7. Aerial view of a center pivot irrigation system irrigating a full circle (A) and a partial circle (B). *Note:* The red outline depicts the circular pattern formed by the rotation of the system and the blue oval highlights the irrigation pipe that distributes the water.

4.1.2 Certificate of Use Compliance

The first step in determining CoU compliance among CPs was to identify the landowner attributes of the CP locations. The landowner data for each county are available via an online GIS portal that can be accessed through the website alabamagis.com. Center pivot irrigation systems were matched with the corresponding parcel of land using the satellite imagery base map. The landowner data included owner name, mailing address, and area of the parcel. The number of parcels for each landowner was grouped by the associated mailing address. Grouping by address instead of by name of the owner accounted for the possibility of a landowner using different names on each parcel he/she owned (such as an alternative name, a spouse's name, or a business name.)

The CoU data supplied by the Alabama OWR contains the "owner name", which was used to link a CoU to the appropriate land parcel owner (Table 3). The latitude and longitude fields could not be used because the coordinates were not for a standardized location, with some at the owner's home and some at a pump site. Pump sites can be located substantial distances from the CP itself, which makes it difficult, if not impossible, to determine which pivots are supplied by the pump. The parcel owner names and CoU owner names were matched to compute the rate of compliance rate for the CoU program in the Wiregrass Region and for each county for the years 2011, 2013, and 2015. It is important to note that a CoU registered pump could supply water to one or more center pivot sites, and that multiple pumps could also supply one center pivot site (Figure 8). Therefore, it was assumed that if the owner of a center pivot pump has a CoU, then all pumps on land owned by that person are registered.

Table 3. Example of the Certificate of Use (CoU) data provided by the Alabama OWR

Water Source	HUC	Name	Certificate Number	Certificate Category	County	Owner Name	Surface /ground water name	Lat.	Long.	Source or Aquifer	Avg. Daily Use	Max Daily Capacity
GW	0314020	Big Creek	000	Irrigation	Lee	Example 1	Well No. 1	32.61	-85.48	Coastal Plain	0.25	0.238
SW	0314020	Big Creek	000	Irrigation	Lee	Example 1	Pond No. 1	32.78	-85.45	Coastal Plain	0.25	0.209

Notes: GW = Groundwater; SW = Surface water; Lat = Latitude; Long = Longitude; Avg = Average; Max = Maximum. Average Daily Use and Max Daily Capacity are reported in units of millions of gallons per day.

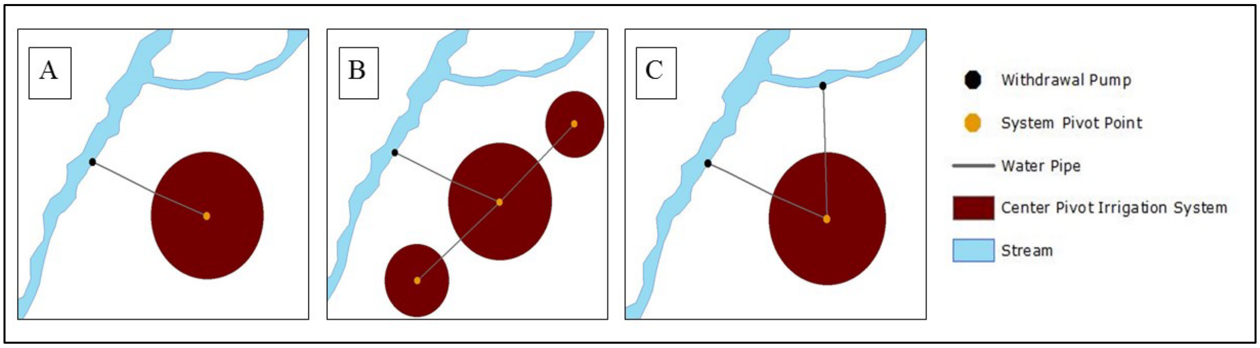


Figure 8. Common configurations of withdrawal pump to center pivot locations: A) one pump, one irrigation system, B) one pump, multiple irrigation systems, and C) two pumps, one irrigation system.

4.1.3 Water Use Estimates

Certificate of Use holders are required to submit their average monthly water use (Table 4). In the example shown in Table 4, Aubie Farms has 3 CoUs with 2 withdrawing surface water from a pond and 1 withdrawing groundwater from a well. As noted previously, it is difficult to link a specific CoU to a specific CP. Therefore, the monthly water use data for each CoU holder was combined to compute that persons total monthly use, which was then used to compute the use for each of that persons CP's based on the area covered by each CP.

For example, in Appendix 2.1 Owner ID 1 has 13 CoUs with all 13 withdrawing groundwater from a well. Owner ID 1 also has 23 CPs irrigating a total of 1753.3 acres, but it is not clear which CPs are associated with which CoUs. To compute the total annual water use by Owner ID 1, the reported water use for each month in MG/Day was multiplied by the number of days in each month for a cumulative total of 897.32 MG. This value was divided by the total area irrigated to estimate the average amount of water applied per acre (0.5106 MG), which could then be used to estimate the amount used by each CP. If Owner ID 1 would have had CoUs withdrawing a combination of surface and groundwater, it would be assumed that the water was distributed proportionally to the CPs. However, this is a major assumption that warrants further investigation.

The monthly water use data provided by each CoU holder who submitted reports as required were used to compute the average use per acre for all users that reported their use, except in cases where the data was clearly incorrect. The result was then used to estimate the volume of water withdrawn by CPs that 1) did not have a CoU or 2) whose owners did not report water use for the year. Since the source (surface or groundwater) was not available for these CPs, no effort was made to estimate the total use for surface water and groundwater.

Table 4. Example of a CoU monthly water use report

Source	Owner	Source Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SW	Aubie Farms	Pond 1	2013	0	0	.08	.15	.5	.8	1	.8	.5	.15	0	0
SW	Aubie Farms	Pond 2	2013	0	0	.08	.08	.5	.8	1	.8	.5	.2	0	0
GW	Aubie Farms	Well 1	2013	0	0	.05	.2	.7	.8	1	.8	.5	.15	0	0

Note: Monthly use amounts are listed in millions of gallons per day or MG/Day.

4.2 Additional Irrigators

Three categories of potential additional irrigators were identified: golf courses, turfgrass farms, and greenhouses/nurseries. Orchards and similar farms that produce high-value fruits or vegetables were included in the greenhouse/nurseries category.

4.2.1 Identification of Potential Additional Irrigators

Internet searches for the businesses that fit one of the three categories identified above were conducted to compile a list of businesses that might be additional irrigators. Figure 9 shows what a Google Maps search for the keywords “golf course” returns. Once potential irrigators for a category were determined, additional searches were conducted to confirm that these businesses were still active. Internet searches were also conducted for businesses with a CoU to verify their locations. The results of both searches were combined to create a list of users and businesses for each of the three additional irrigator categories that could be in need of a CoU.

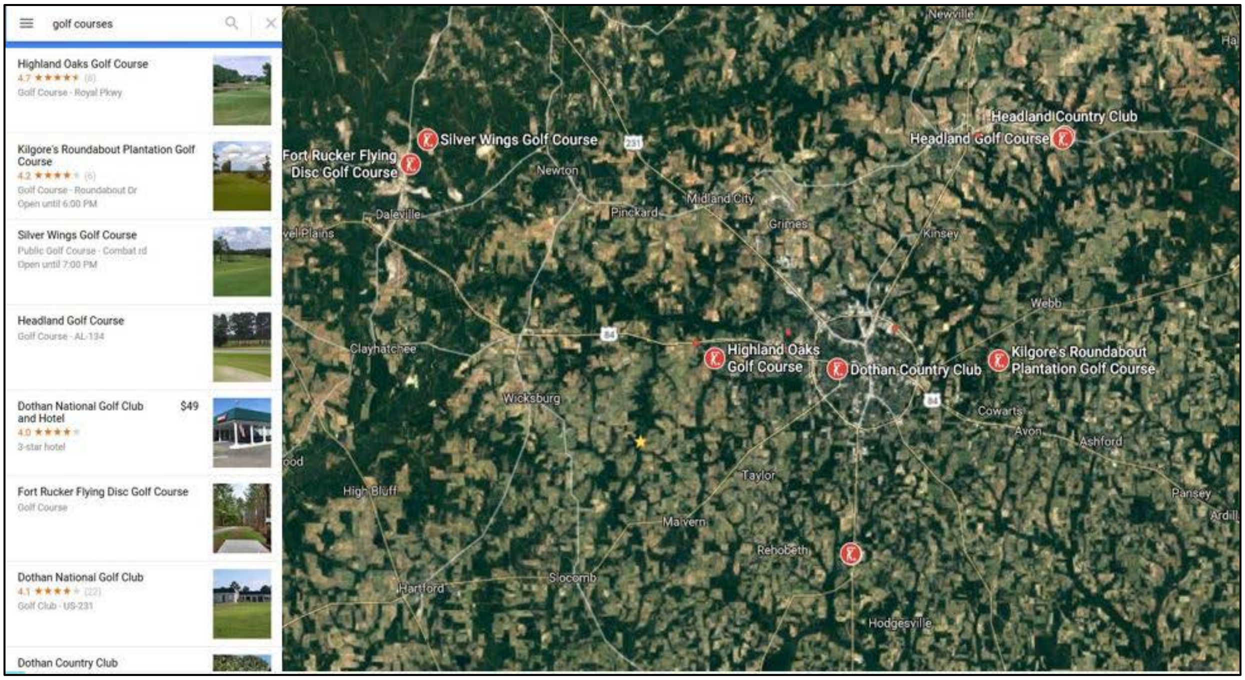


Figure 9. Google Maps search method for additional irrigators. In the image a search for golf courses in the area is being conducted.

4.2.2 Certificate of Use Compliance

Landowner names and mailing addresses were collected for the additional irrigators by using the alabamagis.com online GIS portal for each county in the study area. Certificate of Use compliance rates for each of the additional irrigator categories were calculated by comparing the list of CoU holders with the entire list of potential irrigators, which included those with a CoU. Accurately linking each additional irrigator CoU with the appropriate irrigator category was ensured by 1) comparing the collected landowner information to the CoU holder's name and 2) comparing the CoU holder's name to the business's name and/or the landowner's name. If the irrigated location had at least one CoU, it was considered CoU compliant. Compliance was determined for the Wiregrass Region and by county.

4.2.3 Water Use Estimates

The reported monthly water use daily averages for each golf course were multiplied by the number of days in each month and then added together to get the total annual volume of water in MG/Year withdrawn by each course. Annual total water use was then computed for surface and groundwater sources. Estimated unreported water withdrawals by golf courses were based off reported withdrawal volumes of golf courses and the number of holes on each golf course. The total reported use for the golf courses in the Wiregrass Region was added together and divided by the total number of holes (typically 9 or 18 holes per course) to get the average volume of water in MG/Year/hole. This value was then used to estimate the volume of water for golf courses that did not report their use, based on the number of holes on the course.

Reported annual use for turfgrass farm's and greenhouse/nursery additional irrigators was computed by multiplying the average use per day for each month by the number of days in each month. Estimated unreported water use for the turfgrass farm and greenhouse/nursery additional irrigators category could not be determined because one or more of the following questions could not be answered: 1) the area (acres) the business irrigated, 2) the water source used (i.e., municipal water supply system versus surface/groundwater), or 3) if the facility met the 100,000 GPD withdrawal capacity required for a CoU, which was the case for some of the smaller greenhouse/nurseries.

Chapter 5: Results and Discussion

Irrigation users were divided into two categories for the analysis, center pivot irrigation systems for crop production and additional irrigators (i.e., golf courses, turfgrass farms, and greenhouse/nurseries). This study identified 52 CoU holders in the region with 150 CoUs. However, only 41 of the 52 CoU holders (78.8%) could be accurately matched to an irrigator's land (30 crop production and 11 additional irrigators, with 11 unidentified). Consequently, only 131 of the 150 CoUs (100 crop production and 31 additional irrigators, with 19 unidentified) could be used in the analysis (87.3%) (Appendix 2).

5.1 Center Pivot Irrigation Systems for Crop Production

5.1.1 Inventory of Center Pivot Irrigation Systems

Although the majority of center pivot sites in the study area were used for crop production, this study also found that a substantial number were used for irrigating turfgrass (see below). Therefore, the CPs on turf grass farms are discussed separately in a later section. The number of CPs in the study area increased each year: 2011 (425 crop, 17 turfgrass; 442 total); 2013 (533 crop, 21 turfgrass; 554 total), and 2015 (638 crop, 29 turfgrass; 667 total) (Table 5; Figures 10 and 11). From 2011 to 2015, the number of CPs for crop production increased by 213 (50.9%). The highest number of CPs were located in Houston County, which has 113,640 acres of cultivated crop land (the most crop land of any county). Houston County had the most CPs each year, but Geneva County had the highest rate of increase from 2011 to 2015 (83.5%).

Table 5. Inventory of center pivot irrigation systems by county for 2011, 2013, 2015

County	Number of CPs			Percent (%) Increase		
	2011	2013	2015	2011-2013	2013-2015	2011-2015
Coffee	59	76	84	28.8	10.5	42.4
Dale	33	41	48	24.2	17.1	45.5
Geneva	79	110	145	39.2	31.8	83.5
Henry	84	106	129	26.2	21.7	53.6
Houston	170	200	232	17.6	16.0	36.5
Total	425	533	638	25.4	19.7	50.1

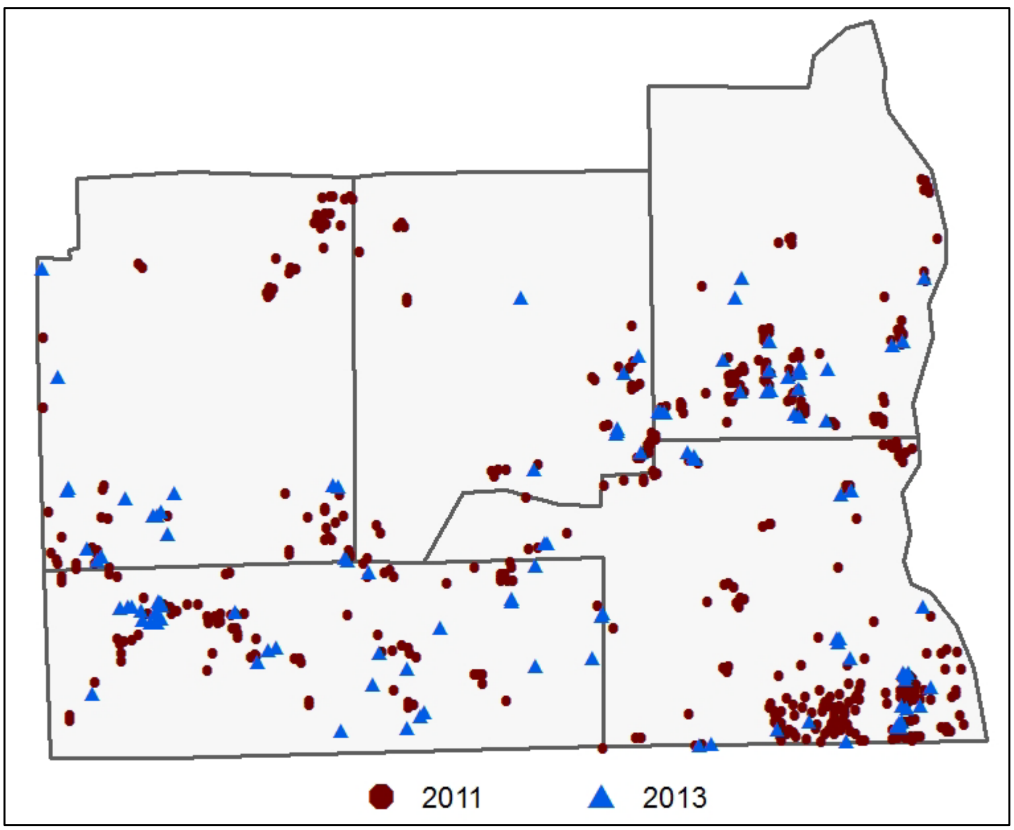


Figure 10. Locations of center pivot irrigation systems in 2011 and new CPs added in 2013.

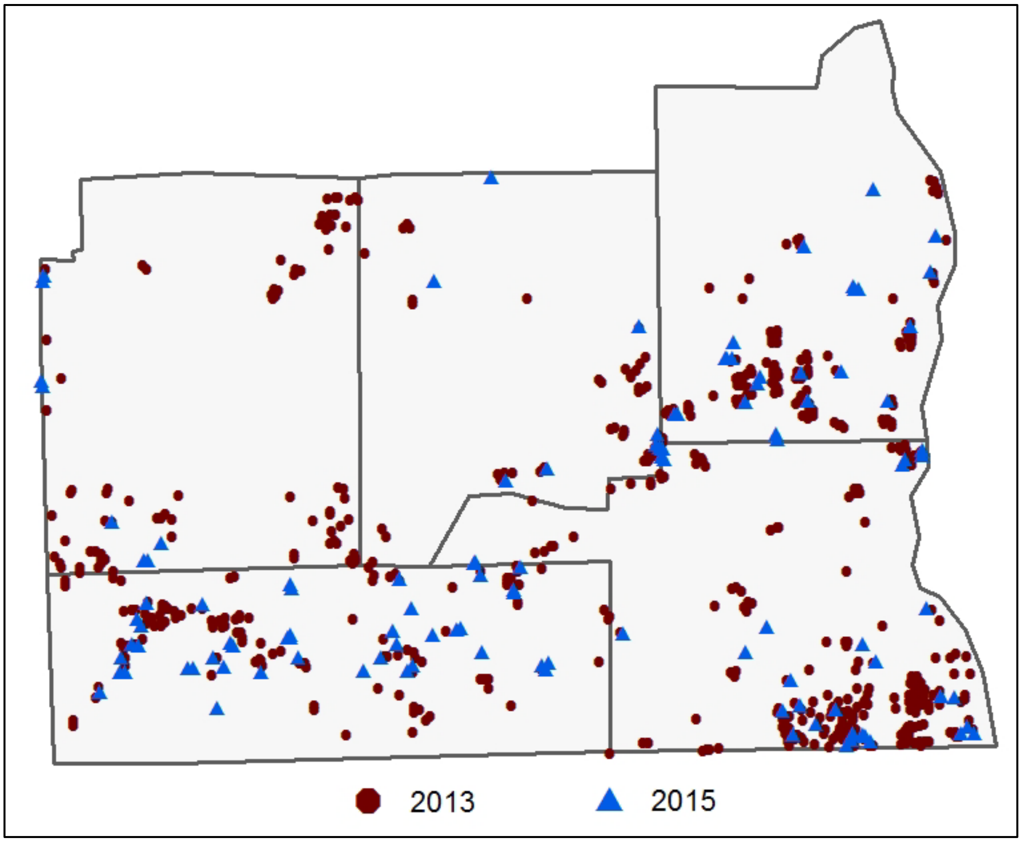


Figure 11. Locations of center pivot irrigation systems in 2013 and new CPs added in 2015.

5.1.2 Certificate of Use Compliance and Water Use Report Compliance

Although the number of CPs increased each year, CoU compliance rate decreased each year. The CoU compliance rate was relatively consistent throughout the study period: 2011 (27.5%), 2013 (24.8%), and 2015 (22.7%) (Table 6; Figure 12). The maximum number of CPs a single owner operated grew from 23 to 29 over the 4-year study period while the minimum stayed at 1. It should be noted that the total number of landowners with a CP on their land, including CP owners without a CoU, increased from 182 to 247. Certificate of Use compliance by county ranged from a high of 32.0% (Houston County) in 2013 to a low of 11.0% (Geneva County) in 2015.

Compliance in submitting water use reports also decreased each year – 2011 (70.1%), 2013 (57.6%), 2015 (53.8%) (Table 6). Compliance with submitting the reports by county varied from a high of 100.0% (Geneva County) in 2011 to a low of 14.3% (Geneva County) in 2013.

Table 6. Certificate of Use compliance and monthly water use reporting by county for 2011, 2013, and 2015.

County	CoU Compliance (%)			Use Reporting Compliance (%) for CP with a CoU		
	2011	2013	2015	2011	2013	2015
Coffee	28.8	25.0	25.0	82.4	36.8	71.4
Dale	21.2	19.5	16.7	85.7	87.5	62.5
Geneva	16.5	12.7	11.0	100.0	14.3	50.0
Henry	31.0	25.5	23.3	50.0	48.1	36.7
Houston	31.8	32.0	30.2	66.7	73.4	55.7
Total	27.5	24.8	22.7	70.1	57.6	53.8

Note: Compliance rates are for users having obtained a CoU at some point in time. Although CoUs have expiration dates, all CoUs were assumed to be active for this analysis.

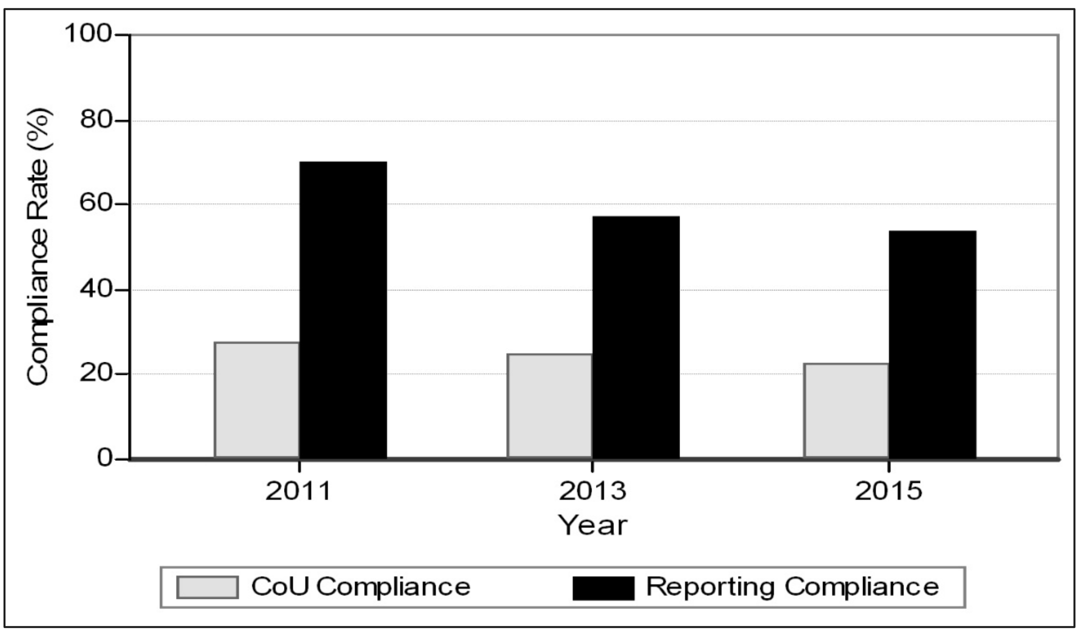


Figure 12. Certificate of Use compliance and monthly water use reporting compliance for center pivot irrigation systems.

5.1.3 Annual Water Use (Reported and Estimated Amounts)

Reported water withdrawals fluctuated over the study period: 2011 (5,425.04 MG), 2013 (1,498.86 MG), and 2015 (3,582.21 MG) (Table 7 and Figure 13). Houston County had the highest reported water use each year with a peak of 1,937.41 MG in 2011 (Table 7).

Some CoU holders reported use data was determined to be inaccurate when attempting to estimate annual water use. More specifically, CPs whose reported water use in 2011 was 0 inches per acre or greater than 30 inches per acre were considered to be errors and were omitted when calculating average use per acre (Appendix 2). Center pivot irrigation systems with reported water use of 0 inches per acres or greater than 25 inches per acre in 2013 were omitted, as were CPs whose reported water use of 0 inches per acres or greater than 27 inches per acre in 2015. The reason for the differences in the set reporting thresholds each year is due to differences in precipitation patterns. When the inaccurate values were removed, the total volume of water in annual millions of gallons (MG) was divided by the total number of acres the remaining CPs irrigated. Based on these adjustments, the results indicated that average use per acre fluctuated over the study period: 2011 (507,702 MG), 2013 (203,886 MG), and 2015 (344,850 MG) (Table 8). The total estimated water withdrawals for CPs with unreported use are as follows: 2011 (8,427.07 MG), 2013 (4,466.30 MG), and 2015 (8,766.06 MG) (Table 7 and Figure 13).

Houston County, which had the highest number of CPs, had the highest total water use each year with the peak in 2011 (5,344.59 MG). Dale County, which had the least number of CPs, had the lowest total water withdrawal each year (Table 7 and Figure 14).

Table 7. Reported use, estimated unreported use, and estimated total water use for center pivot irrigation systems for crop production by county for 2011, 2013, and 2015.

County	Reported Use			Estimated Unreported Use			Estimated Total Use		
	2011	2013	2015	2011	2013	2015	2011	2013	2015
Henry	707.07	405.18	484.46	1638.17	815.59	1728.19	2345.24	1220.77	2212.65
Coffee	1625.55	411.90	1385.27	942.87	608.92	1078.64	2568.42	1020.82	2463.91
Dale	231.35	40.59	71.50	623.56	297.30	587.19	854.91	337.89	658.69
Houston	1937.41	595.37	723.79	3407.18	1504.82	2958.00	5344.59	2100.19	3681.79
Geneva	923.66	45.82	917.19	1815.29	1239.67	2414.04	2738.95	1285.49	3331.23
Total	5425.04	1498.86	3582.21	8427.07	4466.30	8766.06	13852.11	5965.16	12348.27

Note: Values are listed in millions of gallons.

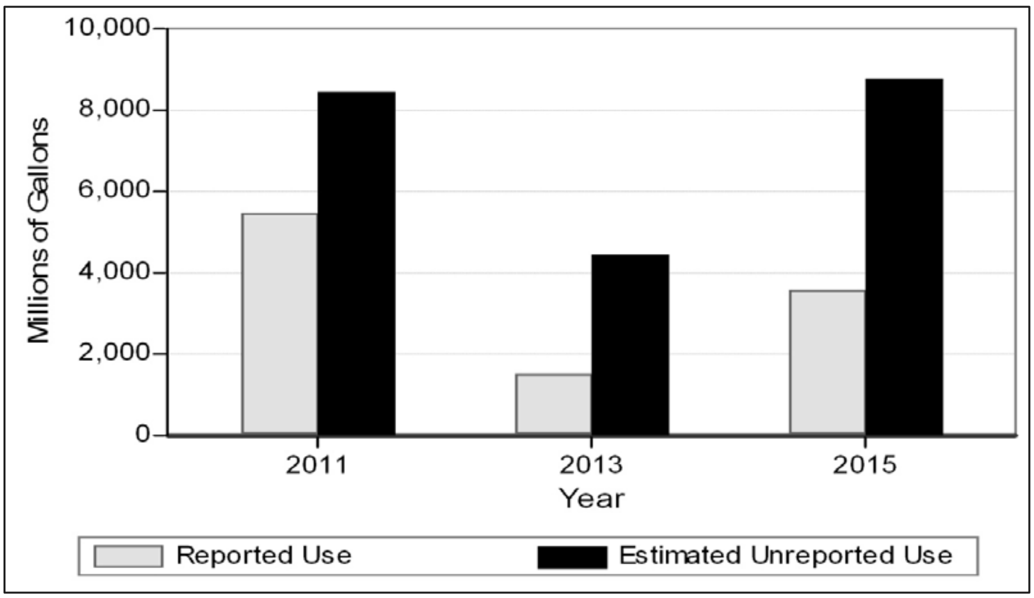


Figure 13. Reported and estimated unreported water use for center pivot irrigation systems in 2011, 2013, and 2015.

Table 8. Average water use per acre for reported center pivot irrigation systems for crop production in 2011, 2013, and 2015.

Year	2011	2013	2015
Acres Irrigated	2,914.81	3,540.56	3,957.35
Gallons Used	,479,856,000.00	721,869,999.95	1,364,691,650.45
Average Gallons Used per Acre	507,702.39	203,885.83	344,849.87

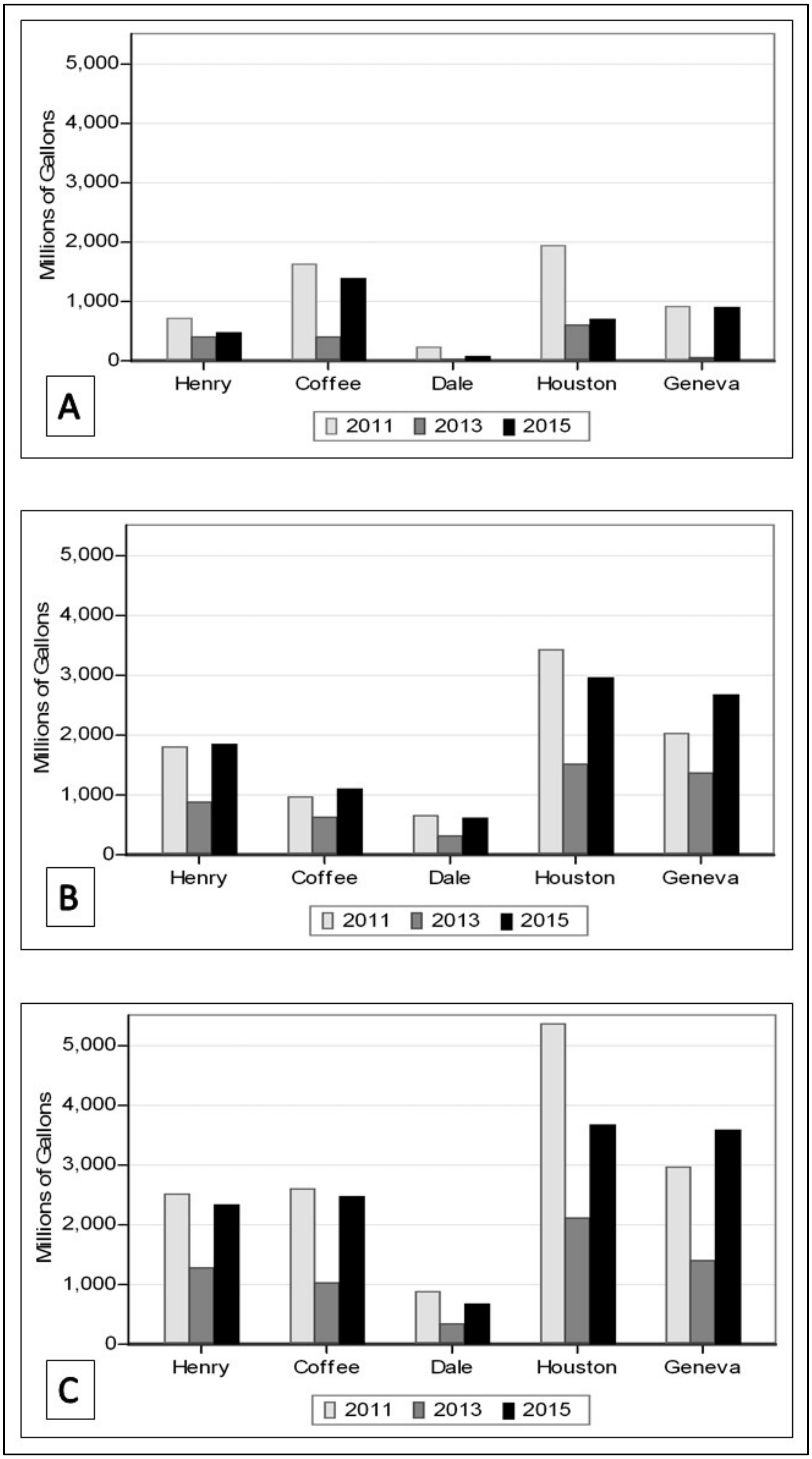


Figure 14. Water withdrawals for center pivot irrigation systems by county: A) Reported B) Estimated Unreported C) Estimated Total.

5.1.4 Surface and Groundwater Usage (Reported Amounts)

Center pivot irrigation systems for crop production reported withdrawing 6.769 billion gallons from surface water sources and 3.725 billion gallons from groundwater sources over the entire 2011-2015 study period (Table 9 and Figure 15). Therefore, surface water was the predominant source for CP irrigation based on the reported use, accounting for 64.5% of the total water withdrawn. Reported surface and groundwater withdrawals were the lowest in 2013 (815.80 MG and 683.06 MG respectively). The largest gap between sources came in 2015, approximately 3.4 times more surface water (2,764.67 MG) was reported withdrawn than groundwater (817.53 MG).

Table 9. Reported water use for center pivot irrigation systems for crop production by withdrawal source.

Year	Source	
	Surface Water	Groundwater
2011	3189.30	2235.74
2013	815.80	683.06
2015	2764.67	817.54
Total	6769.77	3725.34

Note: Values are in millions of gallons

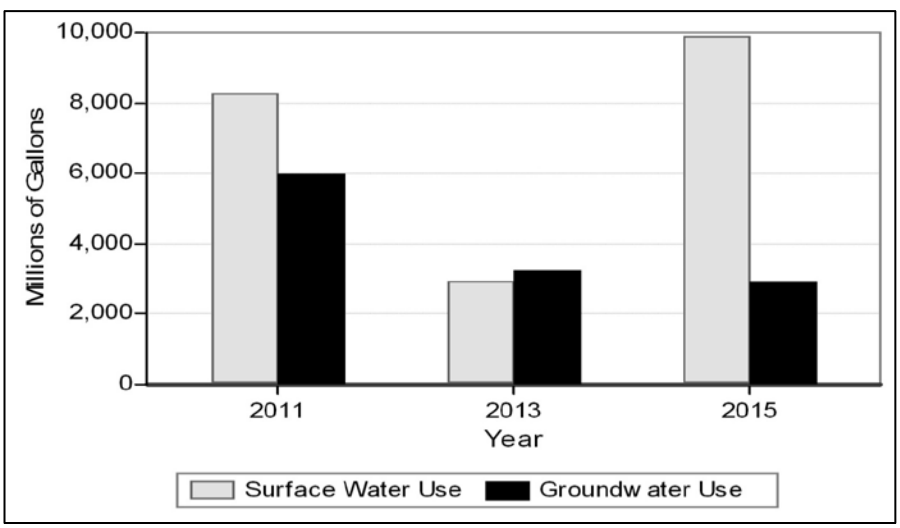


Figure 15. Reported water use for center pivot irrigation systems by source.

5.2 Additional Irrigators

5.2.1 Inventory of Additional Irrigators

This study identified a total of 27 additional irrigators in the study area (11 golf courses, 4 turfgrass farms, and 12 greenhouses or nurseries) (Table 10; Figure 16). Houston County had the most additional irrigators with 9 total (4 golf courses and 5 greenhouses/nurseries), and Henry County had the fewest (3).

Three of the four turfgrass farms were found to be using center pivot irrigation systems, and the number of CPs increased each year 2011 (17), 2013 (21), and 2015 (29) (Table 11). Note that these center pivot sites were verified as turfgrass farms by the company name on the CoU form, the property owner names identified in the Internet search as described earlier, and by visual inspection of the NAIP aerial imagery (Figure 17).

Table 10: Number of additional irrigators by county for 2011-2015.

Additional Irrigator	County				
	Coffee	Dale	Geneva	Henry	Houston
Golf Course (Number of 18-hole courses)	2 (2.5)	1 (0.5)	2 (2.5)	1 (0.5)	5 (5.0)
Turfgrass Farm	1	0	1	2	0
Greenhouse and Nurseries	2	3	2	0	5
Total	5	4	5	3	10

Note: The standard size golf course has 18 holes, but some courses are limited to 9 holes. Also, some businesses irrigated more than one standard size golf course.

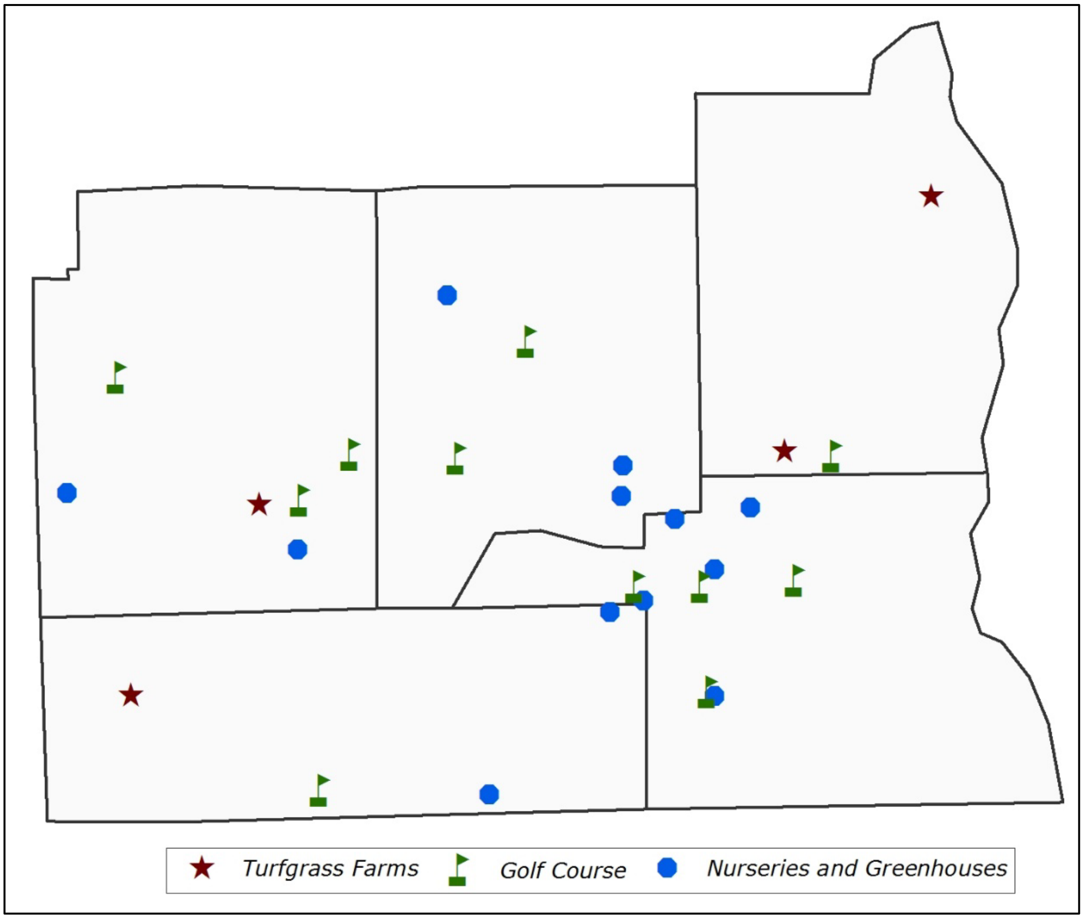


Figure 16. Additional irrigators in Wiregrass study area. The number of turfgrass farms and golf courses remained the same over the study period. It was impossible to determine from the aerial imagery if a nursery/greenhouse was operational in 2011 and 2013; therefore, it is assumed that the number remained the same over the study period.

Table 11: Inventory of center pivot irrigation systems for turfgrass production.

Year	Number of CoUs	Number of CoUs with CPs	Number of CPs with CoUs	Total Number of CPs	Number CPs Imagery Verified
2011	8	6	14	17	13
2013	8	6	18	21	17
2015	8	6	26	29	21

Notes: CoU = Certificate of Use; CP = Center Pivot Irrigation System. National Agriculture Imagery Program data was the imagery used to verify if a center pivot irrigation system irrigated turfgrass.

Figure 17. Aerial view of a center pivot irrigation system irrigating turfgrass. It was determined to be turfgrass due to the landowner owning a turfgrass business in addition to the texture of the grass and the marks left behind from harvesting the turfgrass.

5.2.2 Certificate of Use Compliance and Water Use Report Compliance

Certificate of Use compliance rates among the three categories of additional irrigators were consistent throughout the study period: golf courses (54.5%), turfgrass farms (75%), and greenhouses and nurseries (16.67%) (Table 12). For golf courses with a CoU, the compliance rate for submitting water use reports increased each year: 2011 (50%), 2013 (83.3%), and 2015 (100%). Although only 2 of the possible 12 (16.67%) greenhouses and nurseries in the Wiregrass Region had a CoU, both of them reported withdrawals in 2013 and 2015. Only 1 of the 3 (33.33%) turfgrass farms with a CoU reported withdrawals in 2011 and 2013, and none reported withdrawals in 2015.

Table 12: Certificate of Use compliance and monthly water use reporting for additional irrigators.

Types	CoU Compliance (%)			Withdrawal Reporting Compliance (%)		
	2011	2013	2015	2011	2013	2015
Golf Course	54.5	54.5	54.5	50.0	83.3	100.0
Turfgrass Farm	75.0	75.0	75.0	33.3	33.3	0.0
Greenhouse and Nurseries	16.7	16.7	16.7	0.0	100.0	100.0
Total	40.7	40.7	40.7	36.3	72.7	72.7

Note: Withdrawal reporting compliance is for additional irrigators that have a CoU.

5.2.3 Annual Water Use (Reported and Estimated Amounts)

No effort was made to compute total annual water use for additional irrigators due to inconsistent reporting by turfgrass farms and greenhouse/nursery operations. More specifically, only one of the three turfgrass farms with a CoU submitted reports, and it failed to submit a report in 2015 (Appendix 2). Only two of the greenhouse/nursery irrigators with a CoU submitted reports, and both of them failed to submit a report in 2011 (Appendix 2). Therefore, the remainder of this section focuses on golf courses. The number of courses (18 holes per course) reporting water use doubled from 2011 (3.5) to 2015 (7); however, total use increased by only 27% as the average use per course decreased by 32% (Table 13). Houston County, which has the most golf courses, used the most water for golf courses while Henry County used the least amount (Table 14; Figure 18 and Figure 19).

Table 13. Reported water use for golf courses.

Year	2011	2013	2015
Gallons Used	302,050,000.00	295,664,400.00	413,887,900.00
Number of 18-Hole Courses	3.5	5.5	7.0
Average Use per Course (MG)	86,300,300	53,757,164	59,126,843
Average per Hole (MG)	4,794,444.44	2,986,509.09	3,284,824.60

Note: MG = Millions of Gallons. The volume of water reported used divided by the number of holes of the course results in the average use per hole.

Table 14: Reported use, estimated unreported use, and estimated total water use by golf courses by county for 2011, 2013, and 2015.

County	Reported Use			Estimated Unreported Use			Estimated Total Use		
	2011	2013	2015	2011	2013	2015	2011	2013	2015
Henry	NR	NR	NR	43.15	26.88	29.56	43.15	26.88	29.56
Coffee	NR	64.48	70.07	215.75	80.64	88.69	215.75	145.12	158.76
Dale	NR	63.04	83.55	215.75	53.76	59.13	215.75	116.80	142.68
Houston	249.85	168.15	258.34	172.60	107.51	59.13	422.45	275.66	317.47
Geneva	52.20	0.00	1.93	0.00	0.00	0.00	52.20	0.00	1.93
Total	INC	INC	INC	647.25	268.79	236.51	949.30	564.46	650.40

Note: NR = No Report; INC = Incomplete. Values are recorded in millions of gallons.

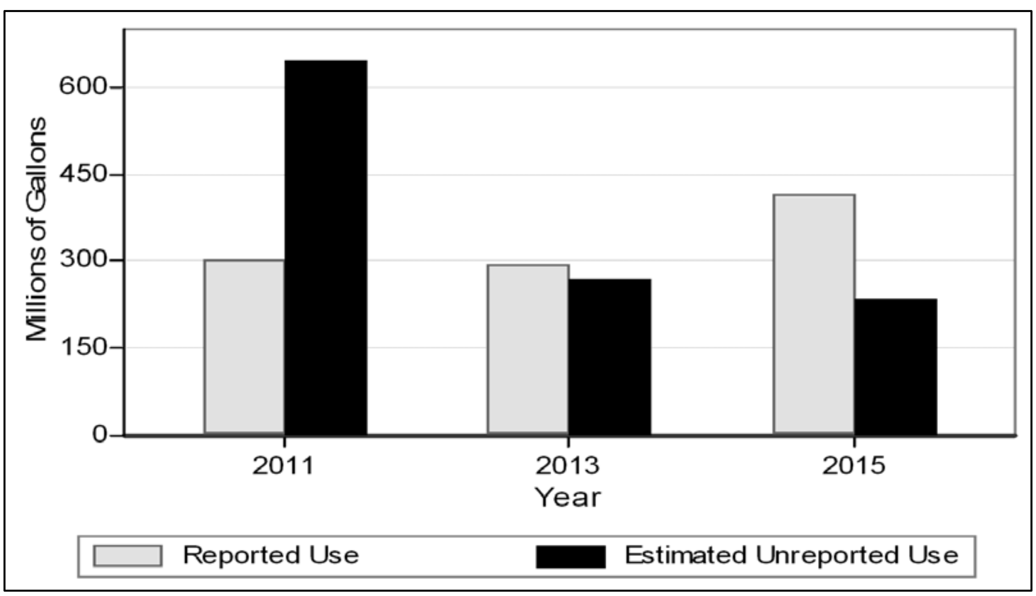


Figure 18. Water use for golf courses 2011, 2013, and 2015.

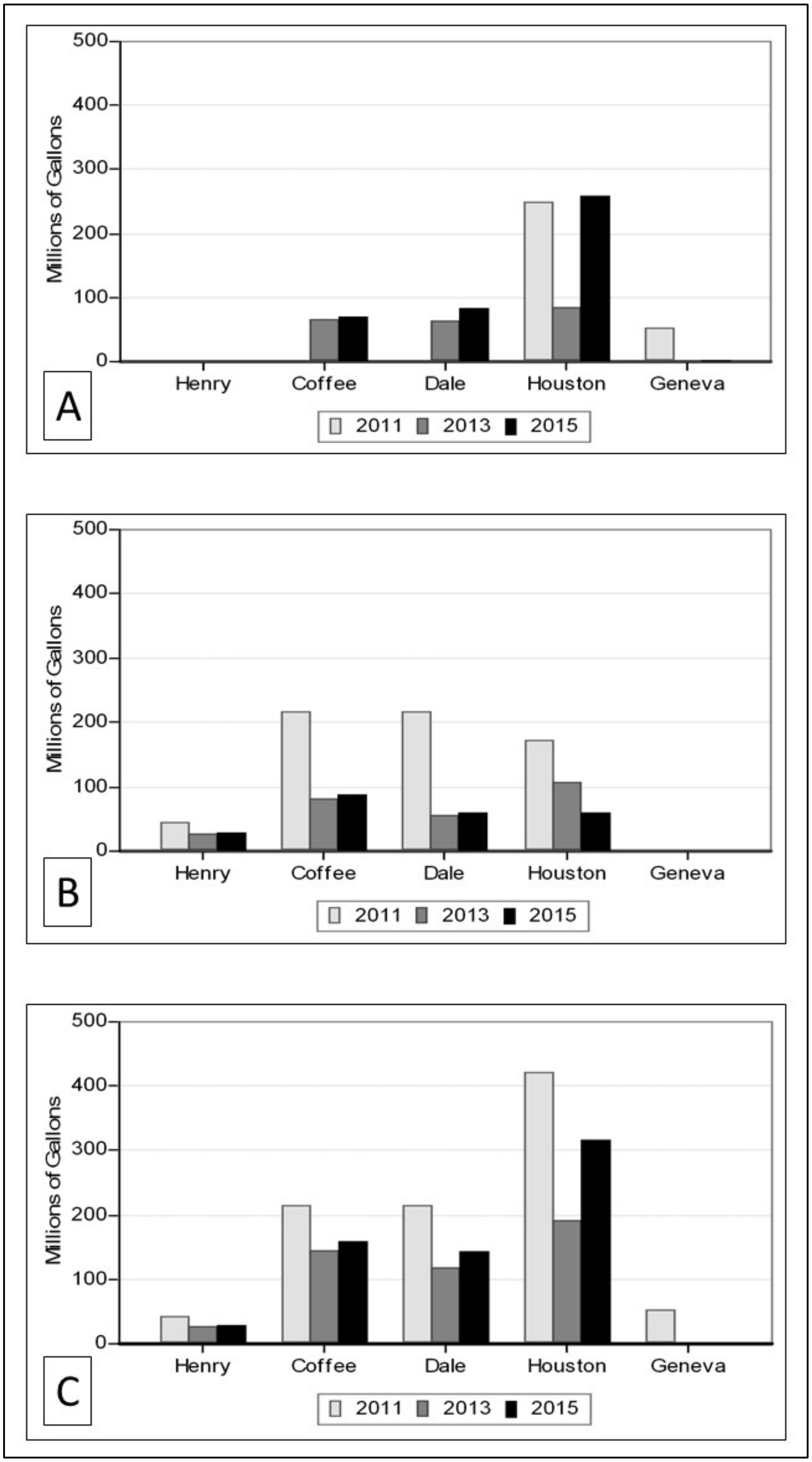


Figure 19. Golf course water withdrawals by county. A) Reported B) Estimated Unreported C) Estimated Total.

5.2.4 Surface and Groundwater Usage (Reported)

The primary source for irrigating golf courses over the study period was surface water (52.33%) (Table 15). Surface water also appeared to be the primary source for irrigating turfgrass farms and greenhouse/nurseries, but inconsistent reporting makes it impossible to be certain.

Table 15. Reported water use for additional irrigators by withdrawal source (surface water vs. groundwater).

Year	Golf Course		Turfgrass		Greenhouse/Nursery	
	SW	GW	SW	GW	SW	GW
2011	123.99	178.07	32.45	0	NR	NR
2013	184.08	111.58	10.62	0	232.90	148.84
2015	221.33	192.56	NR	NR	116.45	148.84
Total	529.40	482.21	INC	INC	INC	INC

Note: Values are listed in millions of gallons. SW = Surface water; GW = Groundwater; NR = No Report; INC = Incomplete.

5.3 Accuracy of Monthly Water Use Reports

The accuracy of the water use reports came into question when analyzing the data (Table 7). For example, Appendix 2.1 shows that Owner ID # 11 had 2 CP's (5 CoUs) and reported applying 531.77 inches of water per acre, and Appendix 2.5 shows that Owner ID # 18 had 2 CP's (2 CoUs) and reported applying 146.36 inches of water per acre. These two cases may be related to errors in counting how many CPs (i.e., area irrigated) they are operating, or to errors in filling out the water use reports such as converting flow rates to total gallons and estimating the time of operation. For instance, some farmers may irrigate twice weekly during the growing season (rather than on a daily cycle) due to issues with managing multiple pumps distributing to multiple CPs, a pumps capacity, area being irrigated, and in response to precipitation patterns (New and Fipps, 2000). Withdrawal volumes can only be deemed 100% accurate if the irrigation system includes meters to monitor the volume of water distributed or to monitor the time the pumps operated, assuming the flow rates are correct (Boken et al. 2004).

The monthly reported water use data were compared with monthly precipitation records to verify the relative accuracy of the reported use data (Figures 20-22). Peak withdrawals should occur during the months of May to August, corresponding to the growing season (NASS, USDA 2010). The data show that water withdrawals followed a bell curve in 2011 and 2015, peaking in June and July. In 2013, withdrawals peaked slightly earlier in the growing season (May and June) due to high precipitation in July (17.85 inches) and August (8.38 inches). Total withdrawals were noticeably lower in 2013 than in 2011 and 2015, which appears to be related to substantially higher precipitation during the growing season in 2013 (May to August; 31.57 inches) compared to 2011 (10.89 inches) and 2015 (17.84 inches). These data show that the pattern in which irrigation was used to supplement natural rainfall during drier months of the growing season fits what one might expect, which suggests that the water use reports are relatively accurate.

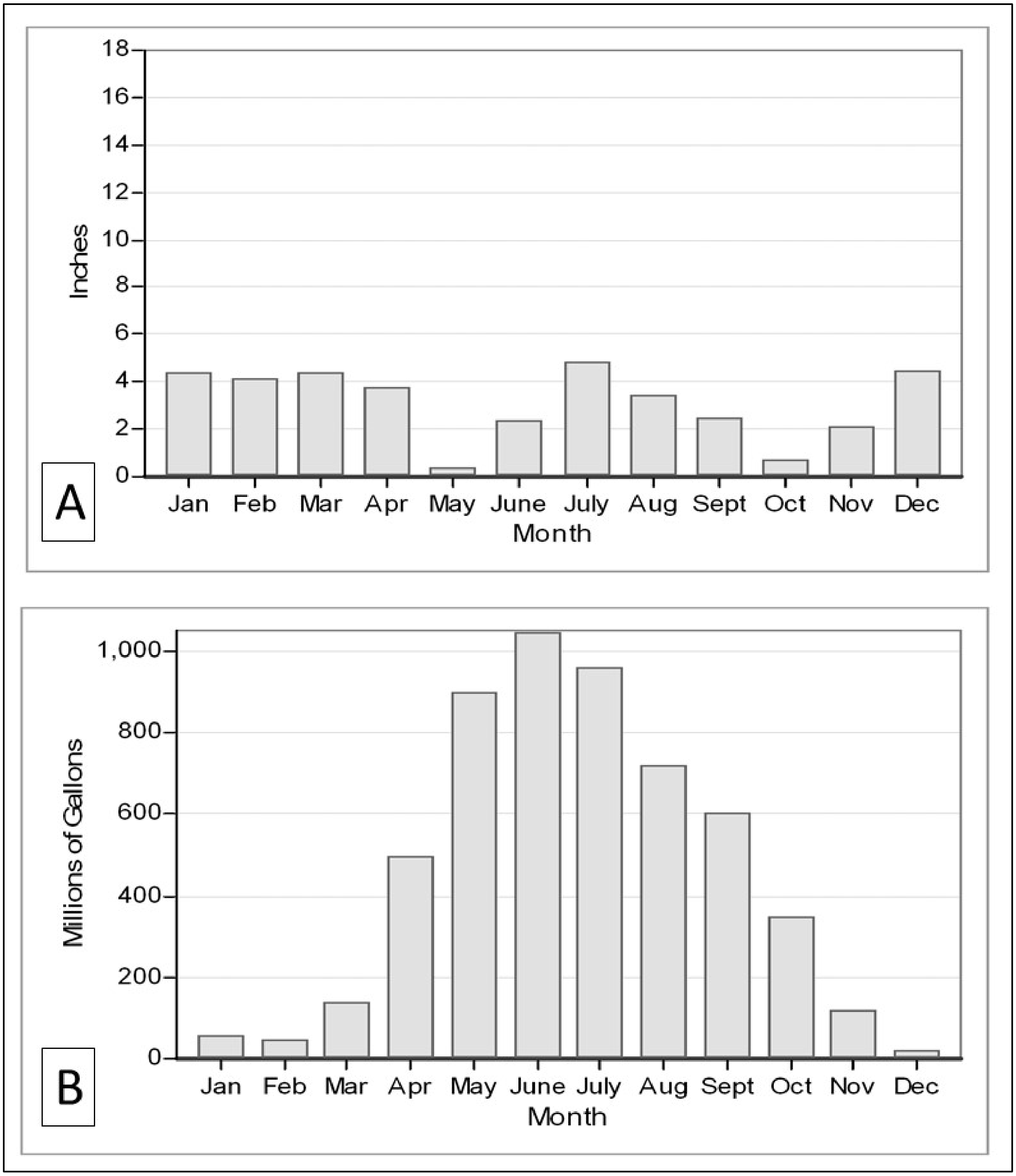


Figure 20. Monthly precipitation and water withdrawals in 2011: A) Average monthly precipitation across the Wiregrass in 2011. (*Source:* NOAA National Climatic Data Center). B) Monthly reported water use by center pivot irrigation systems in 2011. The region received 37.16 inches of precipitation and 5,425 MG of water was reported withdrawn by CPs.

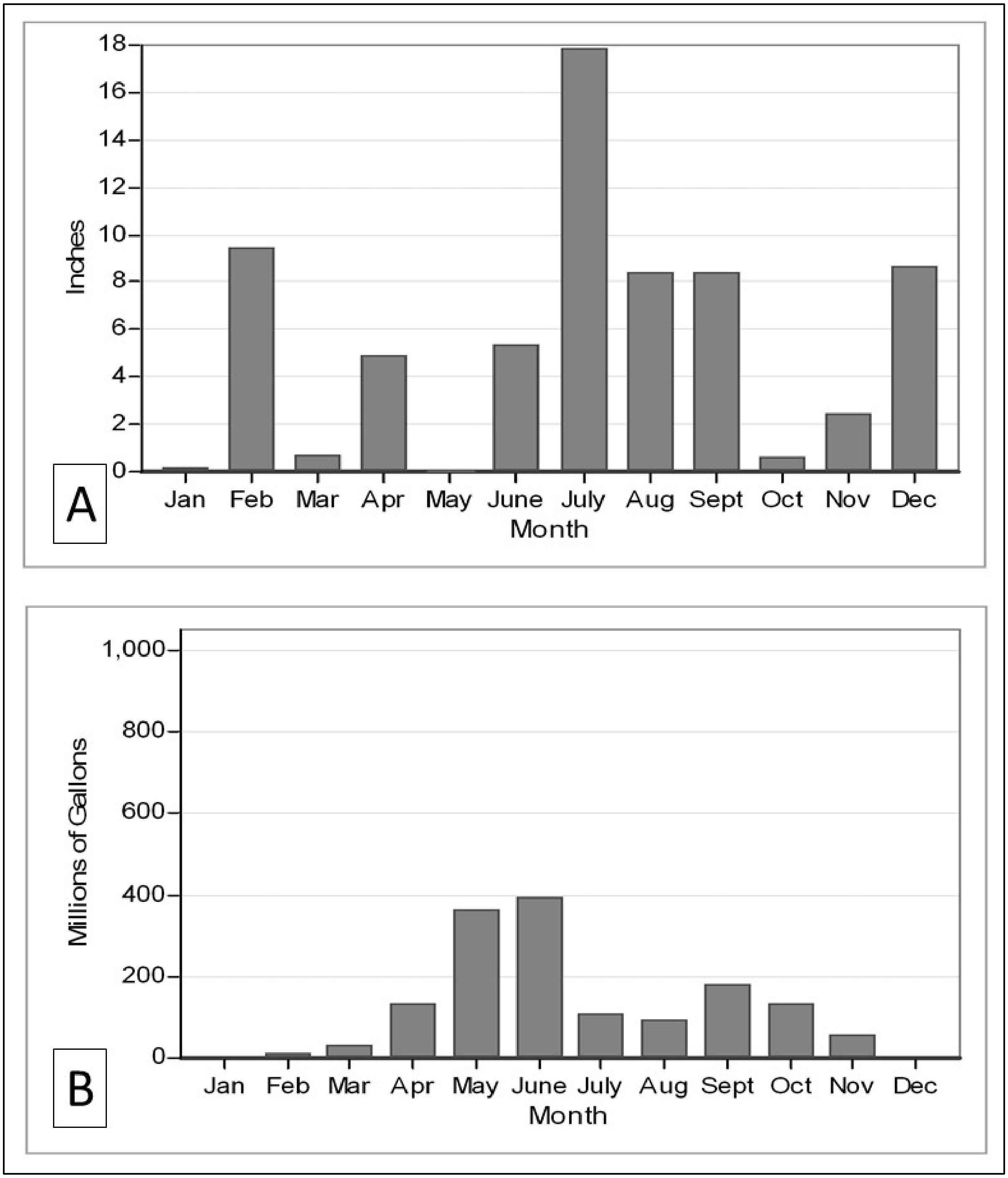


Figure 21. Monthly precipitation and water withdrawals in 2013: A) Average monthly precipitation across the Wiregrass in 2013. (*Source:* NOAA National Climatic Data Center). B) Monthly reported water use by center pivot irrigation systems in 2013. The region received 66.75 inches of precipitation was 1,499 MG of water was reported withdrawn by CPs.

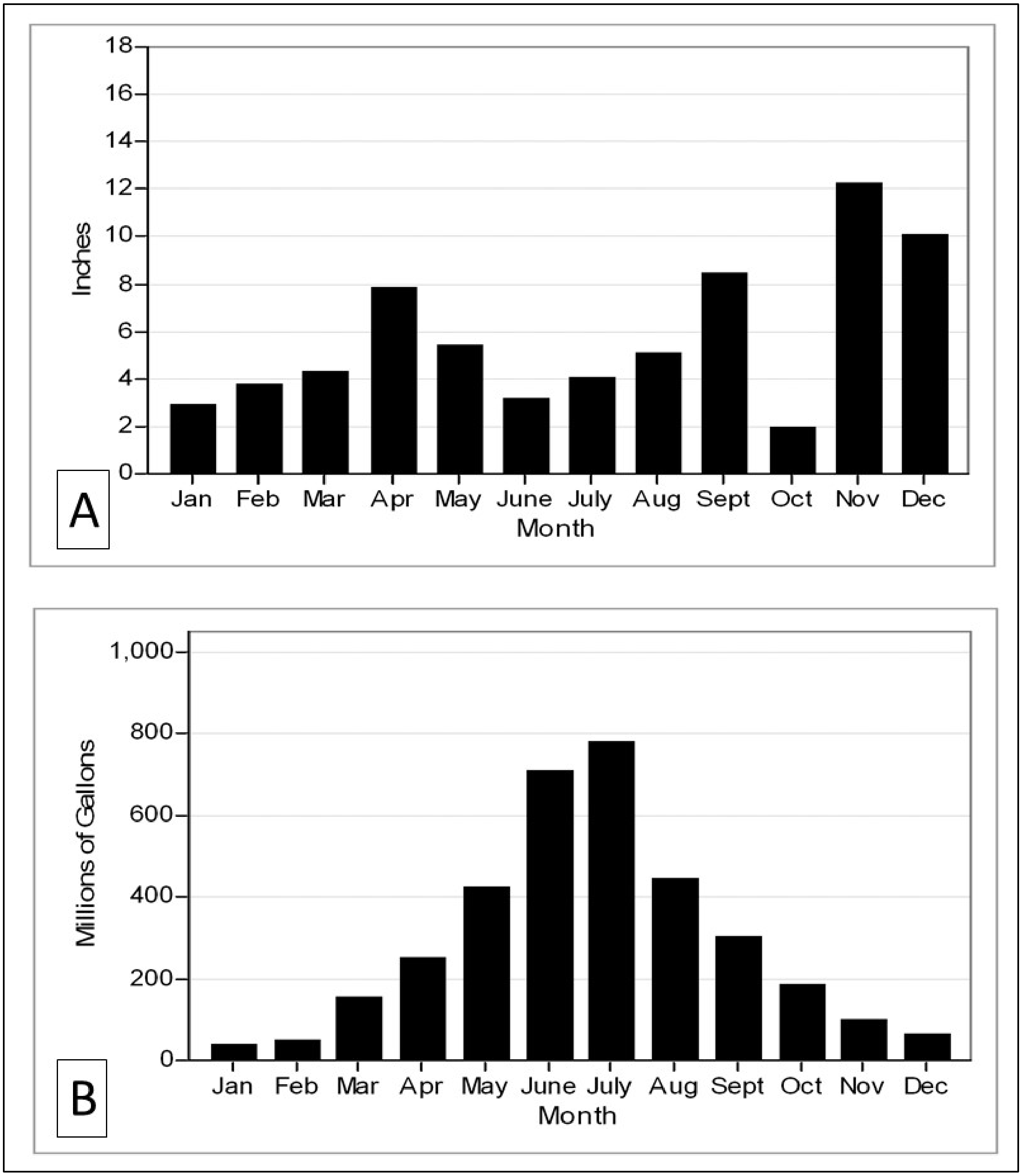


Figure 22. Monthly precipitation and water withdrawals in 2015: A) Average monthly precipitation across the Wiregrass in 2013. (*Source:* NOAA National Climatic Data Center). B) Monthly reported water use by center pivot irrigation systems in 2013. The region received 69.63 inches of precipitation and 3,582 MG of water was reported withdrawn by CPs.

Chapter 6: Summary and Conclusions

Alabama has an abundance of water resources; however, having an abundance of a resource does not eliminate the need to manage it wisely. The state's efforts to address this need include passing the Water Resources Act of 1993, which implemented a Certificate of Use program requiring irrigators with the capacity to withdraw 100,000 GPD or more to apply for a certificate and to report annual water withdrawals. Many states require irrigators to have some form of permit or CoU, but the methods used to monitor or enforce compliance with the regulations vary greatly. A survey of 34 states (27 responses) revealed that monitoring techniques can be grouped into four categories: 1) little or no enforcement, 2) field checks, 3) citizen complaints, and 4) GIS with remote sensing. Alabama's CoU program is an information-gathering program, rather than a regulatory program, in that it does not have an official compliance monitoring or enforcement program and it does not impose a penalty on eligible irrigators who do not participate or fail to submit annual reports; consequently, it falls in the little or no enforcement category.

The purpose of this study was to evaluate the effectiveness of the CoU program in providing information about water withdrawn for irrigation. The study area for this project was the Wiregrass Region of Alabama, which included five counties in the southeastern corner of the state. The study employed the GIS with remote sensing method based primarily on visual interpretation of NAIP imagery. The study focused on four major questions, with the results provided below.

1. How many center pivot irrigation systems are there in the study area?

The total number of center pivot irrigation sites for crop production in the region increased each year: 2011 (425 CPs), 2013 (533 CPs), and 2015 (638 CPs). These data reflect an increase of 50.1% over the study period. Houston County had the highest count each year: 2011 (170), 2013 (200), and 2015 (232), but Geneva County had the highest rate of increase from 2011 to 2015 (83.5%). The study also found that 3 of the 4 turfgrass farms in the region operated center pivot irrigation systems, which also increased in count each year: 2011 (17 CPs); 2013 (21 CPs), and 2015 (29 CPs). Note that the CPs on turfgrass farms were verified by landowner/company owner name and by visual inspection of the aerial imagery. In summary, the total number of all CPs in the region increased each year of the study: 2011 (442); 2013 (554); and 2015 (667).

2. How many center pivot irrigation systems have a Certificate of Use?

The number of CPs with a CoU (for crop production) increased slightly each year: 2011 (117), 2013 (132), and 2015 (145). However, the rate of compliance decreased slightly each year: 2011 (27.5%), 2013 (24.8%), and 2015 (22.7%), which produced an average of 25.0% over the study period. Houston County (30.2%) had the highest rate of CoU compliance in 2015, the final year of the study, which was likely due to the fact that 5 individuals owned 59 of the 70 CoU compliant CPs in the county. A common pattern for CPs with a CoU is that the owner operates multiple CPs. For CPs with a CoU (for crop production), the rate of compliance in submitting annual withdrawal reports also declined each year: 2011 (70.1%), 2013 (57.6%), and 2015 (53.8%).

To better understand these results, it is important to understand the relationship between the number of CPs, the number of CoUs, and the number of farmers who had CoUs. In 2011, there were 27 crop farmers (with CPs) who had CoUs, and these farmers had a total of 96 CoUs for 117 CPs irrigating 6,410.21 acres. In 2013, there were 29 crop farmers (with CPs) who had CoUs, and these farmers had a total of 99 CoUs for 132 CPs irrigating 7,095.42 acres. In 2015, there were also 29 crop farmers (with CPs) who had CoUs, and these farmers had a total of 99 CoUs for 139 CPs irrigating 7,511.85 acres.

Approximately half (49.13%) of CPs that were CoU compliant were operated by farmers who reported annual withdrawals. This relatively high rate was likely due to the fact that these farmers operated multiple CPs. A total of 20 separate CP irrigators reported water use in 2011, 2013, and 2015, with 3 of the 20 reporting only once, 8 reporting twice, and 9 reporting all 3 years. Annual withdrawal reporting compliance rates greatly varied by county each year due to the lack of reporting consistency.

3. What is the total volume of water withdrawn by center pivot irrigators for crop production in the study area?

Total withdrawals fluctuated over the study period: 2011: (13,852.11 MG), 2013 (5,965.16 MG), and 2015 (12,348.27 MG). These amounts were compiled by adding reported withdrawals with estimates of unreported withdrawals for each year: 2011 (5,425.04 MG and 8,427.07 MG, respectively); 2013 (1,498.86 MG and 4,466.30 MG, respectively); and 2015 (3,582.21 MG and 8,766.06 MG, respectively). Note that reported water withdrawal data were used to compute the average number of inches applied per acre, which was then used to estimate unreported withdrawals based on the number of acres covered by CPs that did not have water use reports. The decline in total withdrawals in 2013 was likely due to greater precipitation in the region in the early part of the growing season, which was the wettest year of the study period. The volume of water used by a county was clearly related to the number of CPs in the county, with Houston County withdrawing the greatest amount each year and Dale County withdrawing the least.

The total area irrigated also increased each year: 2011 (6,410.21 ac.), 2013 (7,135.51 ac.), and 2015 (7,524.99 ac.). These data were compiled by adding the area irrigated by CPs that reported withdrawal amounts with the area irrigated by CPs without water use reports: 2011 (4,935.69 ac. and 1,474.61 ac., respectively), 2013 (4,738.19 ac. and 2,397.62 ac., respectively), and 2015 (4,882.40 ac. and 2,642.59 ac., respectively).

4. How many other irrigators (e.g., golf courses, turfgrass farms, greenhouses/nurseries) are there in the study area, how many have a CoU, and what is the total volume of water withdrawn by those additional irrigators?

This study detected a total of 11 golf courses, 4 turfgrass farms, and 12 greenhouses or nurseries that appeared to be potential candidates for a CoU. As noted above, three of the four turfgrass farms used CPs, and the number increased each year: 2011 (17 CPs); 2013 (21 CPs), and 2015 (29 CPs). Golf courses had a consistent CoU compliance rate of 54.5% over the study period, and the rate for submitting annual withdrawal reports increased each year: 2011 (50%), 2013 (83.3%), and 2015 (100%). Turfgrass farms had a CoU compliance rate of 75%, but the rates for reporting withdrawals were low: 2011 (33.3%), 2013 (33.3%), and 2015 (0%). The greenhouse/nursery category is less certain due to the possibility of a business not having the capacity to withdraw 100,000 GPD or the possibility that it relies on a municipal (city water) source. The CoU compliance rate for this category was 16.67% (only 2 of 12 potential businesses had a CoU). Each of those two CoU holders submitted water use reports in 2013 and 2015, but both failed to submit a report in 2011.

Total withdrawals were not computed for the additional irrigators category as a whole due to the incomplete nature of reporting by turfgrass farms and greenhouses/nurseries. Furthermore, it is unclear what area is irrigated for turfgrass farms and greenhouses/nurseries, so it would be difficult to estimate the unreported amounts even with complete reporting. Total withdrawals for golf courses fluctuated over the study period: 2011 (949.30 MG), 2013 (564.46 MG), and 2015 (650.40 MG). These amounts were also based on adding reported withdrawals with estimates of unreported withdrawals: 2011 (302.05 and 647.25 MG, respectively), 2013 (295.67 MG and 268.79 MG, respectively), and 2015 (413.89 MG and 236.51 MG, respectively). The explanation for this pattern is unclear since the number reporting increased each year, but it is likely that precipitation patterns played some role.

6.1 Final Observations

An important finding of this study is that center pivot irrigation for crop production clearly accounted for the overwhelming majority of reported withdrawals in the study area. In 2015 for example, reported withdrawals (total = 4,7272.01 MG) for the four major user categories were as follows: CPs for crop production (3,582.21 MG; 83.85%), golf courses (413.89 MG, 9.69%), turfgrass farms (10.62 MG, 0.25% *assuming 2015 same as 2013 reported amounts), and greenhouse/nurseries (265.29 MG, 6.21%) (Appendix 2.3). Another important finding is that surface water was the primary reported source (as opposed to groundwater) for center pivot irrigation for crop production each year: 2011 (58.8%), 2013 (54.4%), and 2015 (77.2%) (Table 9).

This study also detected several issues in the CoU data that presented challenges in attempting to extract meaningful information about water usage for irrigation in the region. The CoU forms (i.e., separate forms for surface water and groundwater) provided by the Alabama Office of Water Resources for users to complete when applying for a certificate have a good, simple design that also provides options to capture some of the more complex aspects of the design of an irrigation pump and its associated center-pivot irrigation distribution sites. If completed properly, these forms would address some, but not all, of the issues detected in this study.

Firstly, the form is designed to record information about a single pump, such as its pumping capacity and geographic location (latitude and longitude). However, users often provided coordinates for some other location such as their personal residence. Secondly, there is no option (or rather, there is no specific instructions) for designating the number (and location) of center-pivot sites supplied by the pump. Searches of GIS databases of landownership records to overcome these challenges provided some success in locating the likely location of the pump and associated center-pivot irrigation sites, but it is impossible at this point to determine the degree of success. A common problem encountered in conducting these searches is that the CoU holder owned land registered under different names including different combinations/initials, names of family members/relatives, and names of the company/farm. Clearly this search strategy would not detect the location of center-pivot sites located on land registered under the name of a relative with a different last name, or on land leased from a neighbor. Most land leases are short-term leases ranging from 1-3 years, but long-term leases of 20 years or more can occur (Stoneberg 2014) and provide the incentive for the farmer to invest in the land by installing an irrigation system; therefore, long-term leased land is a critical concern. Finally, there does not appear to be a way to determine if a center-pivot site is supplied by two pumps in cases where one withdraws from a surface water source while the other withdraws from a groundwater source. Although this last issue may not be considered a major concern, it presents a problem in attempting to estimate surface and groundwater usage separately.

These issues likely skewed compliance rates in the region as well as reported and estimated unreported amounts of surface and groundwater usage. Therefore, the problems outlined above should be addressed in future updates of the CoU application and reporting program. The lack of a penalty may explain why some potential CoU holders do not participate in the program, but the more likely explanation for most non-participants is that they are unaware of the program. The lack of a penalty may also explain why some CoU holders fail to submit water use reports, but again, they most likely are unaware of this responsibility or simply forgot to collect the data or submit the report. The State of Alabama should consider developing an educational outreach program to address these problems in the future.

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Appendix 1

Methods for Monitoring Compliance with Water Use Regulations by State

A survey of 34 states was conducted in an effort to understand water withdrawal regulations and the methods used to enforce those regulations. An email was sent to a person within each state's agency responsible for water use asking the question "How does (state) go about enforcing and verifying what individuals have the required permits for water withdrawal, and how is it verified that users are using no more than their allocated/self-reported amount of water?" A total of 27 states responded to the survey. The results are detailed in the tables of this appendix.

Appendix 1.1. State Laws on Water Withdrawal Documentation Requirements

State	*Code or Law*	*Withdrawal Amount*
Alabama	Alabama Code Title 9 Statute 9-10B-19 and 20	100,000 GPD
Arkansas	Arkansas Code Ann. 15-22-201 and 15-22-301	Over 10 acre-feet per year
California	California Water Code Division 2 Water Part 2 Chapter 6	Prior Appropriation
Colorado	Colorado Water Code 37-92-103	Prior Appropriation
Connecticut	Connecticut General Statutes 22a-368a	50,000 GPD
Georgia	Georgia State Code 12-5-31	100,000 GPD
Florida	Florida Statutes 27-373 Sections 203 through 250	Varies by water district
Hawaii	Hawaii State Water Code 174C-26	25,000 GPD
Idaho	Idaho Statute 42-701	Prior Appropriation
Indiana	Indiana Code 14-25-7-15	100,000 GPD
Iowa	Iowa Adminstrative Code 567 - 50.7	25,000 GPD
Maryland	Code of Maryland Regulations 26-17.06 and 26-17.07	10,000 GPD
Massachusetts	Massachusetts General Law 2-21G-4 and 11	100,000 GPD or 9,000,000 gallons per 3 month span
Michigan	Michigan Code 324.32723	2,000,000 GPD
Minnesota	Minnesota Statute 103G.271	100,000 GPD
Mississippi	Mississippi Code 51-3-7	20,000 GPD
Missouri	Missouri Statute 256-410-1	100,000 GPD
Montana	Montana Code 85-2-302	Prior Appropriation
Nebraska	Nebraska Code 46-233	Prior Appropriation
New Hampshire	New Hampshire Statutes 488:3 and 488:6	57,600 GPD
New Mexico	New Mexico Statutes 72-1-2	Prior Appropriation
Oklahoma	Oklahoma Code 82-105.9 and 82-105.13	Prior Appropriation
Oregon	Oregon Statute 537.130	Prior Appropriation
South Dakota	South Dakota Code 46-1-15 and 46-5-10	Prior Appropriation
Texas	Texas Water Code 11.022 and 11.031	Prior Appropriation
Utah	Utah Code 73-3-1 and 73-3-2	Prior Appropriation
Virginia	Virginia Code 62.1-243 and 62.1-248	300,000 GPD

Appendix 1.2. Methods for Determining Compliance with Water Withdrawal Laws

State	*1. Little or No Enforcement*	*2. Citizen Complaints*	*3. Field Checks*	*4. GIS/Remote Sensing*	*Total Methods*
Alabama	X				1
Arkansas		X	X		2
California		X	X		2
Colorado		X			1
Connecticut	X				1
Georgia		X	X	X	3
Florida		X	X		2
Hawaii		X			1
Idaho		X	X	X	3
Indiana	X				1
Iowa		X			1
Maryland	X				1
Massachusetts			X		1
Michigan		X			1
Minnesota		X		X	2
Mississippi	X				1
Missouri	X				1
Montana		X			1
Nebraska		X		X	2
New Hampshire			X		1
New Mexico			X		1
Oklahoma		X			1
Oregon			X		1
South Dakota		X	X		2
Texas		X	X		2
Utah		X	X		2
Virginia	X				1
Total	6	16	12	4	

Notes:

1. No official effort to actively monitor compliance.
2. Enforcing agency responds to complaints of noncompliance.
3. Enforcing agency periodically checks for compliance, or when a noncompliance is detected during other activities.
4. Geographic Information Systems are used with remotely sensed data such as aerial photos and satellite imagery to monitor compliance.

Appendix 1.3. Points of Contact for Withdrawal Oversights

State	*Reporting Threshold*	*Person of Contact*
Alabama	100,000 GPD	Littlepage, Tom. Water Management Unit Chief, Alabama Office of Water Resources. January 22, 2016. Conversation
Arkansas	If use over 10 acre-feet a year	Turner, John. Program Coordinator, Arkansas Natural Resource Commission. February 22, 2016. Email Correspondence.
California	Prior Appropriation	Moran, Tim. Public Information Officer, California State Water Resources Control Board. March 3, 2016. Email Correspondence.
Colorado	Prior Appropriation	Deatherage, Jeff. Chief of Water Supply, Division of Water Resources, Colorado Department of Natural Resources. March 2, 2016. Email Correspondence
Connecticut	50,000 GPD	Chase, Cheryl. Director of Inland Water Resources Division, Bureau of Water Protection and Land Reuse, Connecticut Department of Energy and Environmental Protection. February 23, 2016. Email Correspondence.
Georgia	100,000 GPD	Ward, Chris. Environmental Specialist, Georgia Department of Natural Resources. March 2, 2016. Telephone Conversation.
Florida	Varies by water district	Potter, Selina. Bureau Chief of Performance and Compliance Improvement, Northwest Florida Water Management District. March 8, 2016. Email Correspondence.
Hawaii	25,000 GPD	Hardy, Roy. Ground Water Hydrologic Program Manager, Hawaii Commission on Water Resource Management. February 19, 2016. Email Correspondence.
Idaho	Prior Appropriation	Ragan, Brian. Water Compliance Bureau. Idaho Department of Water Resources, February 23, 2016. Email Correspondence.
Indiana	100,000 GPD	Mann, Allison. Division of Water, Indiana Department of Natural Resources. February 19, 2016. Email Correspondence.
Iowa	25,000 GPD	Anderson, Michael. Senior Environmental Engineer, Iowa Department of Natural Resources. February 22, 2016. Email Correspondence.
Maryland	10,000 GPD	Nagle, Christine. Maryland Water Supply Program. March 2, 2016. Email Correspondence.
Massachusetts	100,000 GPD or 9,000,000 gallons in a 3 month span	DUrso, Jen. Water Management Act program enforcement lead, Massachusetts Department of Environmental Protection. February 22, 2916. Email Correspondence.
Michigan	2,000,000 GPD	LeBaron, Andrew. Water Use Program, Michigan Department of Environmental Quality. February 22, 2016. Email Correspondence.

Minnesota	100,000 GPD	Hovey, Tom. Water Regulation Unit Supervisor, Division of Ecological and Water Resources, Minnesota Department of Natural Resources. February 22, 2016. Email Correspondence.
Mississippi	20,000 GPD	Killebrew, Ronn. Mississippi Department of Environmental Quality. February 23, 2016. Email Correspondence.
Missouri	100,000 GPD	Kaden, Scott. Groundwater Section Chief, Water Resources Center, Missouri Geological Survey. February 22, 2016. Email Correspondence.
Montana	Prior Appropriation	Heffner, Millie. Montana Water Rights Bureau Department of Natural Resources and Conservation. March 15, 2016. Telephone Conversation.
Nebraska	Prior Appropriation	Bradley, Jesse. Programs Director Nebraska Department of Natural Resources. February 23, 2016. Telephone Conversation.
New Hampshire	57,600 GPD	Herbold, Stacey. Water Use Registration and Reporting Program, Drinking Water and Groundwater Bureau, New Hampshire Department of Environmental Services. February 23, 2016. Email Correspondence.
New Mexico	Prior Appropriation	Pohl, Jerri. Statewide Projects Supervisor, New Mexico Office of the State Engineer. February 23, 2016. Email Correspondence.
Oklahoma	Prior Appropriation	Wilkins, Kent. Oklahoma Water Resources Board. February 22, 2016. Email Correspondence.
Oregon	Prior Appropriation	Spriet, Jason. Eastern Region Manager, Oregon Water Resources Department. February 24, 2016. Email Correspondence.
South Dakota	Prior Appropriation	Duvall, Ron. Water Rights Program, South Dakota Department of Environment and Natural Resources. February 22, 2016. Email Correspondence.
Texas	Prior Appropriation	Settemeyer, Amy. Texas Watermaster Section Manager, Water Availability Division. March 2, 2016. Email Correspondence.
Utah	Prior Appropriation	Vest, Kurt. Enforcement Engineer, Division of Water Rights, Utah Department of Natural Resources. February 24, 2016. Email Correspondence.
Virginia	300,000 GPD	Nicol, Craig. Water Withdrawal Permitting Program Manager, Virginia Office of Water Supply, Department of Environmental Quality. February 22, 2016. Telephone Conversation.

Appendix 2

Certificate of Use Holder Information Tables

The CoU information tables in this appendix are separated into identified (could be matched to an irrigation system) and unidentified (could not be matched to an irrigation system) CoUs for 2011, 2013, and 2015. Each CoU holder was given an owner ID for confidentiality purposes. Annual surface and groundwater use was computed from the monthly water use reports submitted each year. For each owner, total annual use was divided by the total area irrigated to compute average use per acre. The average inches of water applied per acre was computed to help determine the validity of the reported water use information. The number of CPs each owner had in each county was also listed.

Appendix 2.1. Identified CoUs and their associated water use data for 2011

					Annual Use (MG)							# of CPs				
Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	SW	GW	Total	# CPs	Area (Ac.)	AVG Use/ Acre (MG)	AVG Inches	Coffee	Dale	Geneva	Henry	Houston
1	13	0	13	Crop	NA	897.32	897.32	23	1757.3	0.5106	18.8	0	0	0	0	23
2	2	2	0	Crop	477.16	NA	477.16	2	116.7	4.0867	150.5*	1	0	1	0	0
3	6	1	5	Crop	40.40	718.73	759.13	4	362.6	2.0934	77.09*	0	0	0	0	4
4	4	2	2	Crop	208.25	86.73	294.98	8	333.7	0.8838	32.55*	0	0	8	0	0
5	3	3	0	Crop	248.21	NA	248.21	4	356.9	0.6953	25.61	2	0	2	0	0
6	1	1	0	Crop	157.59	NA	157.59	3	150.0	1.0505	62.19*	3	0	0	0	0
7	14	10	4	Crop	519.23	116.08	635.31	7	438.3	1.4492	53.37*	0	0	0	5	2
8	1	0	1	Crop	NA	231.35	231.35	4	324.5	0.7128	26.25	0	4	0	0	0
9	1	1	0	Crop	57.08	NA	57.08	4	156.4	0.3649	13.44	0	0	0	4	0
10	2	2	0	Crop	0.00	NA	0.00	2	82.6	0.0000	0*	0	2	0	0	0
11	5	5	0	Crop	674.42	NA	674.42	2	46.7	14.4385	531.77*	2	0	0	0	0
12	1	1	0	Crop	35.69	NA	35.69	3	59.6	0.5980	22.02	0	0	0	3	0
13	5	3	2	Crop	180.21	130.04	310.25	2	147.6	2.1013	77.38*	2	0	0	0	0
14	4	2	1	Crop	71.33	54.29	125.62	3	144.0	0.8720	32.11*	3	0	0	0	0
15	1	1	0	Crop	0.00	NA	0.00	1	25.9	0.0000	0*	1	0	0	0	0
16	2	2	0	Crop	249.75	0.00	249.75	1	51.6	4.8392	178.21*	0	0	0	1	0
17	8	1	7	Crop	0.00	10.21	10.21	7	259.8	0.0393	1.45	0	0	0	0	7
18	2	2	0	Crop	174.17	0.00	174.17	2	120.7	1.4430	53.14*	0	0	2	0	0
20	2	1	1	Crop	NR	NR	UK	2	137.1	UK	UK	0	0	0	0	2
21	2	1	1	Crop	NR	NR	UK	3	114.6	UK	UK	0	0	0	3	0
22	3	2	1	Crop	NR	NR	UK	7	359.3	UK	UK	0	0	0	0	7
23	2	2	0	Crop	NR	NA	UK	1	30.7	UK	UK	0	1	0	0	0
24	1	1	0	Crop	NR	NA	UK	3	60.9	UK	UK	3	0	0	0	0
25	2	2	0	Crop	NR	NA	UK	3	86.1	UK	UK	0	0	0	3	0
27	5	4	1	Crop	NR	NR	UK	12	370.1	UK	UK	0	0	0	7	5
28	2	1	1	Crop	NR	NR	UK	2	132.9	UK	UK	0	0	0	0	2
29	2	1	1	Crop	NR	NR	UK	2	182.6	UK	UK	0	0	0	0	2
31	2	2	0	Turf	NR	NA	UK	9	485.6	UK	UK	3	0	6	0	0
32	4	0	4	Turf	NA	NR	UK	5	336.1	UK	UK	0	0	0	5	0
33	2	2	0	Turf	32.45	NA	32.45	0	UK	UK	UK	0	0	0	0	0
34	1	1	0	Golf Course (27 holes)	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
35	4	0	4	Golf Course (18 holes)	NA	31.36	31.36	0	UK	UK	UK	0	0	0	0	0
36	1	1	0	Golf Course (18 holes)	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
37	2	1	1	Golf Course (18 holes)	NR	NR	UK	0	UK	UK	UK	0	0	0	0	0

38	2	2	0	Golf Course (9 holes)	52.20	NA	52.20	0	UK	UK	UK	0	0	0	0	0
39	4	2	2	Golf Course (36 holes)	71.78	146.70	218.49	0	UK	UK	UK	0	0	0	0	0
40	6	2	4	Nursery	NR	NR	UK	0	UK	UK	UK	0	0	0	0	0
41	3	4	0	Nursery	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
Total (Crop)	96	54	42	27	INC	INC	INC	117	INC	INC	INC	17	7	13	26	54
Total (Others)	31	17	14	11	INC	INC	INC	14	INC	INC	INC	3	0	6	5	0
Total (All)	127	71	56	38	INC	INC	INC	131	INC	INC	INC	20	7	19	31	54

Note: Ac. = Acres; AVG = Average; MG = Millions of Gallons; SW = Surface Water; GW = Groundwater; NA = Not Applicable; INC = Incomplete; Inches = Inches of water applied per acre; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated); * = Values not used when estimating average water use by CPs.

Appendix 2.2. Unidentified CoUs and their associated use data for 2011

Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	Annual SW Use (MG)	Annual GW Use (MG)	Annual Total Use (MG)	# CPs	AVG Inches	County
19	1	1	0	Crop	NR	NR	UK	UK	UK	Houston
26	2	2	0	Crop	NR	NR	UK	UK	UK	Coffee
30	1	1	0	Crop	NR	NR	UK	UK	UK	Houston
42	1	1	0	UK	NR	NR	UK	UK	UK	Dale
43	1	1	0	UK	NR	NR	UK	UK	UK	Henry
44	1	1	0	UK	NR	NR	UK	UK	UK	Dale
45	2	2	0	UK	NR	NR	UK	UK	UK	Coffee
46	1	1	0	UK	NR	NR	UK	UK	UK	Houston
47	3	1	2	UK	NR	NR	UK	UK	UK	Houston
48	2	0	2	UK	NA	0	0	UK	UK	Houston
49	2	0	2	UK	NA	0.82	0.82	UK	UK	Houston
50	2	2	0	UK	NR	NR	UK	UK	UK	Coffee
51	2	1	1	UK	NR	NR	UK	UK	UK	Houston
52	2	0	2	UK	NR	NR	UK	UK	UK	Houston
Total (Crop)	4	4	0	3	INC	INC	INC	UK	UK	
Total (UK)	19	10	9	11	INC	INC	INC	UK	UK	
Total (All)	23	14	9	14	INC	INC	INC	UK	UK	

Note: The user type "crop" is based on later (2013,2015) reports and imagery taken prior to 2011. AVG = Average; MG = Millions of Gallons; Inches = Inches of water applied per acre; SW = Surface Water; GW = Groundwater; INC = Incomplete; NA = Not Applicable; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated).

Appendix 2.3. Identified CoUs and their associated data for 2013

Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	Annual Use (MG) SW	GW	Total	# CPs	Area (Ac.)	AVG Use/ Acre (MG)	AVG Inches	# of CPs Coffee	Dale	Geneva	Henry	Houston
1	13	0	13	Crop	NA	390.16	390.16	29	1935.7	0.2016	7.42	0	0	0	0	29
2	2	2	0	Crop	NR	NA	UK	4	227.6	UK	UK	2	0	2	0	0
3	6	1	5	Crop	NR	65.67	65.67	6	514.5	0.1276	4.70	0	0	0	0	6
4	4	2	2	Crop	NR	NR	UK	8	331.0	UK	UK	0	0	8	0	0
5	3	3	0	Crop	41.58	NA	41.58	4	365.4	0.1138	11.90	2	0	2	0	0
6	1	1	0	Crop	NR	NA	UK	3	149.4	UK	UK	3	0	0	0	0
7	14	10	4	Crop	262.29	63.13	327.43	7	438.3	0.7469	27.51*	0	0	0	5	2
8	1	0	1	Crop	NA	38	38	4	321.8	0.1181	4.35	0	4	0	0	0
9	1	1	0	Crop	11.47	NA	11.47	5	202.0	0.0568	2.09	0	1	0	4	0
10	2	2	0	Crop	0	NA	0	2	82.6	0.0000	0*	0	2	0	0	0
11	5	5	0	Crop	NR	NA	UK	2	46.7	UK	UK	2	0	0	0	0
12	1	1	0	Crop	15.47	NA	15.47	3	56.9	0.2719	10.01	0	0	0	3	0
13	5	3	2	Crop	170.85	85.77	256.62	2	147.5	1.7380	64.00*	2	0	0	0	0
14	4	2	1	Crop	44.7	38.33	83.03	3	144.0	0.8303	21.23	3	0	0	0	0
15	1	1	0	Crop	NR	NA	UK	1	26.1	UK	UK	1	0	0	0	0
16	2	2	0	Crop	192.95	0	192.95	1	55.0	3.5025	128.99*	0	0	0	1	0
17	8	1	7	Crop	0	0	0	7	258.5	0.0000	0*	0	0	0	0	7
18	2	2	0	Crop	NR	NA	UK	2	121.0	UK	UK	0	0	2	0	0
19	1	1	0	Crop	0	NR	0	1	78.1	0.0000	0*	0	0	0	0	1
20	2	1	1	Crop	0	NR	0	2	137.1	0	0*	0	0	0	0	2
21	2	1	1	Crop	NR	NR	UK	3	112.8	UK	UK	0	0	0	3	0
22	3	2	1	Crop	NR	NR	UK	7	359.5	UK	UK	0	0	0	0	7
23	2	2	0	Crop	NR	NA	UK	1	31.4	UK	UK	0	1	0	0	0
24	1	1	0	Crop	NR	NA	UK	3	61.3	UK	UK	3	0	0	0	0
25	2	2	0	Crop	NR	NA	UK	3	86.1	UK	UK	0	0	0	3	0
26	2	2	0	Crop	NR	NA	UK	1	37.1	UK	UK	1	0	0	0	0
27	5	4	1	Crop	NR	NR	UK	13	450.8	UK	UK	0	0	0	8	5
28	2	1	1	Crop	NR	NR	UK	2	132.9	UK	UK	0	0	0	0	2
29	2	1	1	Crop	NR	NR	UK	3	222.7	UK	UK	0	0	0	0	3
31	2	2	0	Turf	NR	NA	UK	13	642.2	UK	UK	3	0	10	0	0
32	4	0	4	Turf	NA	NR	UK	5	336.1	UK	UK	0	0	0	5	0
33	2	2	0	Turf	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
34	1	1	0	Golf Course (27 holes)	63.04	NA	63.04	0	UK	UK	UK	0	0	0	0	0
35	4	0	4	Golf Course (18 holes)	NA	14.57	14.57	0	UK	UK	UK	0	0	0	0	0

36	1	1	0	Golf Course (18 holes)	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
37	2	1	1	Golf Course (18 holes)	NR	64.48	64.48	0	UK	UK	UK	0	0	0	0	0
38	2	2	0	Golf Course (9 holes)	0	NA	0	0	UK	UK	UK	0	0	0	0	0
39	4	2	2	Golf Course (36 holes)	56.56	97.01	153.57	0	UK	UK	UK	0	0	0	0	0
40	6	2	4	Nursery	232.9	148.84	381.74	0	UK	UK	UK	0	0	0	0	0
41	3	4	0	Nursery	0	NA	0	0	UK	UK	UK	0	0	0	0	0
Total (Crop)	99	57	42	29	INC	INC	INC	132	INC	INC	INC	19	8	14	27	64
Total (Others)	31	17	14	11	INC	INC	INC	18	INC	INC	INC	3	0	10	5	0
Total (All)	130	74	56	40	INC	INC	INC	150	INC	INC	INC	22	8	24	32	64

Note: Ac. = Acres; AVG = Average; MG = Millions of Gallons; SW = Surface Water; GW = Groundwater; NA = Not Applicable; INC = Incomplete; Inches = Inches of water applied per acre; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated); * = Values not used when estimating average water use by CPs.

Appendix 2.4. Unidentified CoUs and their associated use data for 2013

Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	Annual SW Use (MG)	Annual GW Use (MG)	Annual Total Use (MG)	# CPs	AVG Inches	County
30	1	1	0	Crop	NR	NR	UK	UK	UK	Houston
42	1	1	0	UK	NR	NR	UK	UK	UK	Dale
43	1	1	0	UK	12.95	NA	12.95	UK	UK	Henry
44	1	1	0	UK	NR	NR	UK	UK	UK	Dale
45	2	2	0	UK	NR	NR	UK	UK	UK	Coffee
46	1	1	0	UK	NR	NR	UK	UK	UK	Houston
47	3	1	2	UK	NR	NR	UK	UK	UK	Houston
48	2	0	2	UK	NA	0	0	UK	UK	Houston
49	2	0	2	UK	NA	0.82	0.82	UK	UK	Houston
50	2	2	0	UK	68.63	NR	68.63	UK	UK	Coffee
51	2	1	1	UK	NR	NR	UK	UK	UK	Houston
52	2	0	2	UK	NR	NR	UK	UK	UK	Houston
Total (Crop)	1	1	0	1	INC	INC	INC	UK	UK	
Total (UK)	19	10	9	11	INC	INC	INC	UK	UK	
Total (All)	20	11	9	12	INC	INC	INC	UK	UK	

Note: The known user type "crop" is based on imagery taken prior to 2011. AVG = Average; MG = Millions of Gallons; Inches = Inches of water applied per acre; SW = Surface Water; GW = Groundwater; INC = Incomplete; NA = Not Applicable; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated).

Appendix 2.5. Identified CoUs and their associated use data for 2015

					Annual Use (MG)							# of CPs				
Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	SW	GW	Total	# CPs	Area (Ac.)	AVG Use/ Acre (MG)	AVG Inches	Coffee	Dale	Geneva	Henry	Houston
1	13	0	13	Crop	NA	363.18	363.18	29	1935.2	0.1876	6.91	0	0	0	0	29
2	2	2	0	Crop	379.85	NR	379.85	5	257.0	1.4780	54.43*	2	0	3	0	0
3	6	1	5	Crop	NR	229.39	229.39	7	530.1	0.4327	15.94	0	0	0	0	7
4	4	2	2	Crop	NR	NR	UK	8	333.7	UK	UK	0	0	8	0	0
5	3	3	0	Crop	252.7	NA	252.7	4	356.9	0.6916	26.06	2	0	2	0	0
6	1	1	0	Crop	534.3	NA	534.3	4	192.4	2.7763	102.25*	3	0	1	0	0
7	14	10	4	Crop	240.26	67.62	307.88	7	438.3	0.7023	25.86	0	0	0	5	2
8	1	0	1	Crop	NA	64.3	64.3	4	324.5	0.1998	7.3	0	4	0	0	0
9	1	1	0	Crop	31.85	NA	31.85	5	202.0	0.1576	5.8	0	1	0	4	0
10	2	2	0	Crop	NR	NA	UK	2	82.6	UK	UK	0	2	0	0	0
11	5	5	0	Crop	313.78	NA	313.78	2	46.7	6.7176	247.4*	2	0	0	0	0
12	1	1	0	Crop	NR	NA	UK	4	82.1	UK	UK	0	0	0	4	0
13	5	3	2	Crop	172.6	50.18	222.78	2	147.6	1.5088	55.56*	2	0	0	0	0
14	4	2	1	Crop	59.95	42.85	102.81	3	144.0	1.0281	26.28	3	0	0	0	0
15	1	1	0	Crop	12.58	NA	12.58	1	25.9	0.4852	17.87	1	0	0	0	0
16	2	2	0	Crop	283.14	NA	283.14	2	105.3	2.6868	98.95*	0	0	0	2	0
17	8	1	7	Crop	NR	NR	UK	8	269.7	UK	UK	0	0	0	0	8
18	2	2	0	Crop	483.66	NA	483.66	2	121.7	3.9742	146.36*	0	0	2	0	0
19	1	1	0	Crop	0	NA	0	1	54.1	0.0000	0*	0	0	0	0	1
20	2	1	1	Crop	NR	NR	UK	3	160.8	UK	UK	0	0	0	0	3
21	2	1	1	Crop	NR	NR	UK	4	125.1	UK	UK	0	0	0	4	0
22	3	2	1	Crop	NR	NR	UK	7	359.3	UK	UK	0	0	0	0	7
23	2	2	0	Crop	NR	NA	UK	1	31.4	UK	UK	0	1	0	0	0
24	1	1	0	Crop	NR	NA	UK	3	60.9	UK	UK	3	0	0	0	0
25	2	2	0	Crop	NR	NA	UK	3	86.1	UK	UK	0	0	0	3	0
26	2	2	0	Crop	NR	NA	UK	3	200.8	UK	UK	3	0	0	0	0
27	5	4	1	Crop	NR	NR	UK	16	494.6	UK	UK	0	0	0	8	8
28	2	1	1	Crop	NR	NR	UK	2	132.9	UK	UK	0	0	0	0	2
29	2	1	1	Crop	NR	NR	UK	3	222.7	UK	UK	0	0	0	0	3
31	2	2	0	Turf	NR	NA	UK	21	834.1	UK	UK	3	0	18	0	0
32	4	0	4	Turf	NA	NR	UK	5	336.1	UK	UK	0	0	0	5	0
33	2	2	0	Turf	NR	NA	UK	0	UK	UK	UK	0	0	0	0	0
34	1	1	0	Golf Course (27 holes)	83.55	NA	83.55	0	UK	UK	UK	0	0	0	0	0
35	4	0	4	Golf Course (18 holes)	NA	8.12	8.14	0	UK	UK	UK	0	0	0	0	0

36	1	1	0	Golf Course (18 holes)	81.93	NA	81.93	0	UK	UK	UK	0	0	0	0	0
37	2	1	1	Golf Course (18 holes)	NR	70.07	64.48	0	UK	UK	UK	0	0	0	0	0
38	2	2	0	Golf Course (9 holes)	1.93	NA	1.93	0	UK	UK	UK	0	0	0	0	0
39	4	2	2	Golf Course (36 holes)	53.92	114.37	168.29	0	UK	UK	UK	0	0	0	0	0
40	6	2	4	Nursery	116.45	148.84	265.29	0	UK	UK	UK	0	0	0	0	0
41	3	4	0	Nursery	0	NA	0	0	UK	UK	UK	0	0	0	0	0
Total (Crop)	99	57	42	29	INC	INC	INC	145	INC	INC	INC	21	8	16	30	70
Total (Others)	31	17	14	11	INC	INC	INC	26	INC	INC	INC	3	0	18	5	0
Total (All)	130	74	56	40	INC	INC	INC	171	INC	INC	INC	24	8	34	35	70

Note: Ac. = Acres; AVG = Average; MG = Millions of Gallons; SW = Surface Water; GW = Groundwater; NA = Not Applicable; INC = Incomplete; Inches = Inches of water applied per acre; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated); * = Values not used when estimating average water use by CPs.

Appendix 2.6. Unidentified CoUs and their associated use data for 2015

Owner ID	# CoUs	# SW CoUs	# GW CoUs	User Type	Annual SW Use (MG)	Annual GW Use (MG)	Annual Total Use (MG)	# CPs	Avg Inches	County
30	1	1	0	Crop	NR	NA	UK	UK	UK	Houston
42	1	1	0	UK	403.35	NA	403.35	UK	UK	Dale
43	1	1	0	UK	0	NA	0	UK	UK	Henry
44	1	1	0	UK	NR	NA	UK	UK	UK	Dale
45	2	2	0	UK	0	NA	0	UK	UK	Coffee
46	1	1	0	UK	NR	NA	UK	UK	UK	Houston
47	3	1	2	UK	NR	NR	UK	UK	UK	Houston
48	2	0	2	UK	NA	0	0	UK	UK	Houston
49	2	0	2	UK	NA	0	0	UK	UK	Houston
50	1	1	0	UK	73.6	NA	73.6	UK	UK	Coffee
51	2	1	1	UK	NR	NR	UK	UK	UK	Houston
52	2	0	2	UK	NA	NR	UK	UK	UK	Houston
Total (Crop)	1	1	0	1	INC	INC	INC	UK	UK	
Total (UK)	19	10	9	11	INC	INC	INC	UK	UK	
Total (All)	20	11	9	12	INC	INC	INC	UK	UK	

Note: The known user type “crop” is based on imagery taken prior to 2011. AVG = Average; MG = Millions of Gallons; Inches = Inches of water applied per acre; SW = Surface Water; GW = Groundwater; INC = Incomplete; NA = Not Applicable; NR = No Report (the CoU owner did not submit a water use report); UK = Unknown (the information could not be calculated).