No. 142, Original

In The
Supreme Court of the United States

STATE OF FLORIDA,

Plaintiff,

v.

STATE OF GEORGIA,

Defendant.

DIRECT TESTIMONY OF SUAT IRMAK, Ph.D.

October 26, 2016

TABLE OF CONTENTS

I, Suat Irmak, Ph.D., offer the following as my Direct Testimony.

I. INTRODUCTION AND OVERVIEW OF MY OPINIONS

1. I have been retained by the State of Georgia as an expert in agricultural water management and conservation, crop water use, evapotranspiration, and irrigation efficiency. I have been asked to evaluate and render an expert opinion on: (i) the purpose and necessity of agricultural irrigation in the Georgia portion of the ACF Basin; (ii) Georgia's management and stewardship of agricultural water resources in the ACF Basin; (iii) whether Georgia's estimates of agricultural water use in the ACF Basin are based on reliable and accurate methodologies and data; and (iv) whether irrigators in ACF Georgia are using water efficiently.

2. *First*, the high precipitation variability and low water-holding capacity of soils in ACF Georgia make irrigation during the growing season necessary for sustaining crop productivity. Lack of sufficient water for even a short period can impose extreme stress on crops in the region, reducing yield and possibly causing total crop failure. Agricultural irrigation in the ACF Basin is not a "discretionary" practice, but is instead a requirement for sustaining the agricultural industry in ACF Georgia.

3. *Second*, Georgia is a responsible, proactive, and conscientious steward of agricultural water resources. In the late 1990s, in response to evidence that agricultural irrigation might be impacting streamflows, Georgia took responsible regulatory measures to study and manage agricultural irrigation. I have studied Georgia's statutory and regulatory initiatives, and other programs, and I will discuss and highlight those efforts. I have evaluated those efforts in light of my experience in agricultural water management and policy. In my opinion, there is substantial evidence of a strong commitment by Georgia to promote efficient and responsible agricultural water use, improve irrigation efficiency, and enact proactive and meaningful programs to manage agricultural water resource challenges.

4. *Third*, Georgia's estimates of total agricultural water use, which are testified to by Dr. Wei Zeng, are based on reliable methods and data. Georgia has invested significant resources, time, and effort to estimate the total amount of water withdrawals for irrigation and other agricultural uses in the ACF Basin. I have reviewed Georgia's methodology for calculating irrigation withdrawals from surface and groundwater sources for agricultural

purposes, as well as its approach to estimating total agricultural consumptive water use. In my opinion, Georgia's methodology is sound and reflects the best available estimates of agricultural water use in the ACF Basin that impacts streamflow.

5. *Fourth*, the majority of farmers in Georgia's ACF Basin are irrigating in an efficient manner. I calculated crop water use requirements and agricultural productivity in the Flint River Basin, and compared that data to agricultural metering data. Overall, I found that 67.5% of Georgia farmers irrigated less than the adjusted crop irrigation requirement. Agricultural productivity and crop water use efficiency also have been increasing in Georgia since the 1990s, indicating that Georgia farmers have been achieving increasingly higher crop yields per unit of water used.

II. BACKGROUND AND PROFESSIONAL QUALIFICATIONS

6. I am the Harold W. Eberhard Distinguished Professor of Biological Systems Engineering at the University of Nebraska-Lincoln Institute of Agriculture and Natural Resources.

7. I have a Ph.D. (2002) in Agricultural and Biological Engineering from the University of Florida. I have an M.S. (1996) in Soil and Water Resources and Irrigation Engineering from Mediterranean University in Antalya, Turkey. I have a B.Sc. (1993) in Agricultural Structures and Irrigation Engineering from Çukurova University in Adana, Turkey, which is one of the top agricultural and irrigation engineering universities in Europe.

8. I am an expert in the fields of agricultural engineering, agricultural water resource management, and soil and water conservation. I have 28 years of experience in the field of agricultural engineering, which is a broad discipline that includes agricultural resource management (including water use), water conservation, irrigation engineering, soil management and conservation, and climatology and atmospheric sciences. I have 25 years of experience measuring and calculating crop water use, which is determined from crop evapotranspiration ("ET"). I have extensive experience measuring, calculating, and modeling crop ET, soil-water dynamics, and the relationship between crop water use, crop yields, and environmental and climatic factors.

9. I am the founder and leader of the Nebraska Agricultural Water Management Network. The Network, which is composed of over 1,400 Nebraska farmers, is the largest and most comprehensive agricultural water management network in the nation. The Network focuses on enhancing agricultural water use efficiency.

10. I am one of the founders of UNL's South Central Agricultural Laboratory Irrigation Engineering and Water Management Research Facility. The research facility focuses on studying how best to manage agricultural water resources in order to use water efficiently, improve agricultural conservation measures, and enhance crop productivity under different irrigation methods.

11. I manage over 2,000 acres of agricultural research fields. Throughout my career, I have worked on real-world irrigation practices with irrigators, agricultural professionals, and state and federal agency personnel to help them best utilize agricultural water resources. I have intimate knowledge of agricultural irrigation practices, agricultural water management, and the various real-world challenges faced by farmers and irrigators in different regions.

12. I have conducted hundreds of large-scale field research projects on best practices for agricultural water resource management and crop water use efficiency. I have firsthand experience with operating various types of irrigation systems that exist today, including center pivots, surface and subsurface drip irrigation systems, surface (or gravity) and low-pressure irrigation systems.

13. I teach advanced graduate-level courses on soil and water resources, irrigation engineering, water management, crop water use efficiency, energy balance and evapotranspiration, and land surface-microclimate interactions.

14. I have published numerous papers on irrigation efficiency and crop water use. For instance, I have authored leading papers on developing standards and practices for calculating crop ET. My research and education activities in soil and water resources engineering have been adopted and implemented nationally by the U.S. Department of Agriculture's Natural Resource Conservation Service ("USDA-NRCS").

15. I have chaired national committees on irrigation management, ET, and consumptive water use. I have also chaired a task committee on crop coefficients. I am currently the chair of, or a member of, numerous committees on crop water use, irrigation engineering, and soil and water conservation.

16. My experience not only covers irrigation management, irrigation efficiency, and soil and water conservation, but also the impact of policies, rules, and regulations on the agricultural industry and irrigation practices. I am regularly invited to speak before state and federal government bodies regarding agricultural water resource management, best practices for irrigation, and other subjects. I have developed expertise and understanding of how governmental policies can influence on-farm irrigation practices and other aspects of day-to-day agricultural water use and management.

17. During my 8 years of research at the University of Florida for my Ph.D. program, I studied the soil and water resource characteristics of the humid/sub-humid climatic conditions of the Apalachicola-Chattahoochee-Flint (“ACF”) River Basin. I participated in numerous field research projects in Georgia and Florida, and developed familiarity with the agricultural industry in both states. As part of my research in the ACF Basin, I also conducted analyses of the soil physical properties and evaluated the soil moisture levels of fine sandy soils of the type found in southwest Georgia.

18. I have published over 270 publications, including 165 peer-reviewed journal articles, 2 book chapters, 45 professional society conference technical papers, 40 peer-reviewed extension and outreach articles, 27 educational articles, and numerous technical reports. I serve as a scientific reviewer for 13 national and international journals on agricultural water management, ET and surface energy balance, irrigation engineering, hydrology, water resources research, agronomy, and soil science. I have also given over 400 presentations to various groups entities, including conferences, research institutions, government agencies, and universities.

19. I have received 60 national, international, and regional awards for my research and education programs. Additional details about my background and accomplishments are provided in my CV. GX-1027 (Dr. Irmak CV).

III. IRRIGATION IS IMPORTANT FOR AGRICULTURAL PRODUCTION IN ACF GEORGIA

20. Because of the physical and climatic characteristics of Georgia's ACF Basin, irrigation is necessary for sustaining meaningful agricultural production. Irrigation greatly increases crop yields, crop quality, gross and net return, and land values. Contrary to the testimony of certain Florida experts, irrigation is not a "discretionary" practice in the Georgia portion of the ACF Basin but is essential to maintaining crop productivity in that region.[1] Two factors are important to understanding why irrigation is important: (1) soil conditions and (2) precipitation patterns.

A. Soil Conditions

21. The water holding capacity of a soil is an important characteristic for understanding the necessity and reasonableness of irrigation. Available water capacity, also called soil water holding capacity, is a standard measure of how much water a particular soil type can contain. In general, the higher the percentage of larger particles (e.g., silt and clay-sized particles), the larger the surface area and the greater the ability of the soil to hold water. The smaller percentage of larger particles (e.g., sandy soil), the lower the ability to hold water.[2] Because they have a lower ability to retain water, sandy soils require more frequent irrigation applications than silty, silty-clay, silty loam, or silty-clay loam soils.

22. Usable soil water is similar to, but distinct from, available water capacity. Not all of the water held in the soil type is available for uptake by the crop. Usable soil water refers to the amount of water that can be stored in the soil that is also available for uptake by the crop. GX-1246 (USDA Handbook). Usable soil water generally "is considered to be 50 percent of the water holding capacity" of soil. GX-1235 (Physical Properties of Soil and Soil Water); *see also* GX-1246 (USDA Handbook) (40 to 60 percent).

---

[1] From a purely definitional perspective, irrigation, like any other practice, is "discretionary." However, the real issue facing farmers from an agricultural perspective is the yield risk associated with a lack of irrigation. Given the soil and climate conditions in Georgia, this yield risk is very high and, as a practical matter, renders irrigation necessary for stable farming.

[2] The amount of organic material in a soil also affects available water capacity. As the level of organic matter increases in a soil, the available water capacity also increases, in large part because of the affinity of organic matter for water. As a general matter, sandy and sandy-loam soils have low organic matter content.

- GX-1246 is a true and accurate copy of a publication from the USDA entitled National Engineering Handbook Chapter 2: Irrigation Water Requirements at 2-147 (1993). Experts in my field regularly rely on such publications, and I reviewed this work in preparing my expert opinions.

- GX-1235 is a true and accurate copy of a publication entitled Soils - Part 2: Physical Properties of Soil and Soil Water (2016), from the University of Nebraska-Lincoln Plant & Soil Sciences eLibrary, which is publicly available at https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=10&maxto=10. Experts in my field regularly rely on such publications, and I reviewed this work in preparing my expert opinions.

23. As part of my work in this case, I calculated available water capacity and usable soil water for soils in the ACF Basin in Georgia. In doing so, I found that ACF Georgia has very sandy soils, and that the available water capacity and usable soil water of most agricultural soils in the Georgia portion of the ACF Basin are low. In his written testimony, Dr. Sunding takes issue with my calculations and argues that I understate the ability of soils in ACF Georgia to retain water. Sunding Direct Testimony at ¶¶ 99-102. Dr. Sunding misunderstands my testimony on this issue.

24. In calculating available water capacity and usable soil water, I relied on the USDA Natural Resource Conservation Service's Web Soil Survey, the same source on which Dr. Sunding relied. *Id.* ¶ 27. I agree with Dr. Sunding that the average available water capacity value in ACF Georgia is approximately 1.29 inches per foot of soil. *Id.* ¶ 102. However, that only tells half of the story. As I have explained, usable soil water is generally considered to be around 50% of available water capacity, and usable soil water is what is important for evaluating how much water is actually available for crops to uptake to maintain growth and produce yield. With an average available water capacity value of 1.29 inches per foot, the average usable soil water value in the ACF Basin is approximately 0.65 inches per foot of soil. That means that, for each foot of soil layer, crops in ACF Georgia are able to take up only 0.65 inches of water. In contrast, the agricultural regions of Nebraska that grow corn and soybeans (peanuts and cotton are not generally grown in Nebraska) have predominantly silt-loam soils, which tend to have far higher available water capacities and usable soil water. For example, numerous counties in Nebraska have soils with average available water capacities of 2.2 inches per foot or higher, meaning usable soil water in those counties is about 1.1 inches per foot. *See, e.g.*, FX-187 (Available Water Capacities for Nebraska Counties) at 3, 6, 11, 18, 20, 22, 23.

25. In addition to having a lower available water capacity and usable soil water than soils elsewhere in the country, soils in the ACF Basin also have higher saturated hydraulic conductivity values than other types of soils. Saturated hydraulic conductivity refers to how easily water can move through the soil. Agricultural soils in Midwestern and Western states have hydraulic conductivity values ranging from 0.05 inch/hr to 1.5 inch/hr, whereas agricultural soils prevalent in the ACF have a 4.5 inch/hr saturated hydraulic conductivity value. GX-1236 (Saturated Hydraulic Conductivity in Relation to Soil Texture). As a result, water percolates below the crop root zone much more quickly in the ACF Basin than it does in other areas, and crops in the ACF Basin have less ability or opportunity to uptake water before it leaves the root zone. More irrigation is therefore required to ensure that crops uptake the required amounts of water. Indeed, because of the high hydraulic conductivity values in ACF Georgia, additional irrigation can be required even shortly after a precipitation event.

- GX-1236 is a true and accurate copy of a chart published by the USDA-NRCS entitled Saturated Hydraulic Conductivity in Relation to Soil Texture. It is publicly available available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074846. Experts in my field regularly rely on such government published charts, and I reviewed this work in preparing my expert opinions.

B. Precipitation and Climate

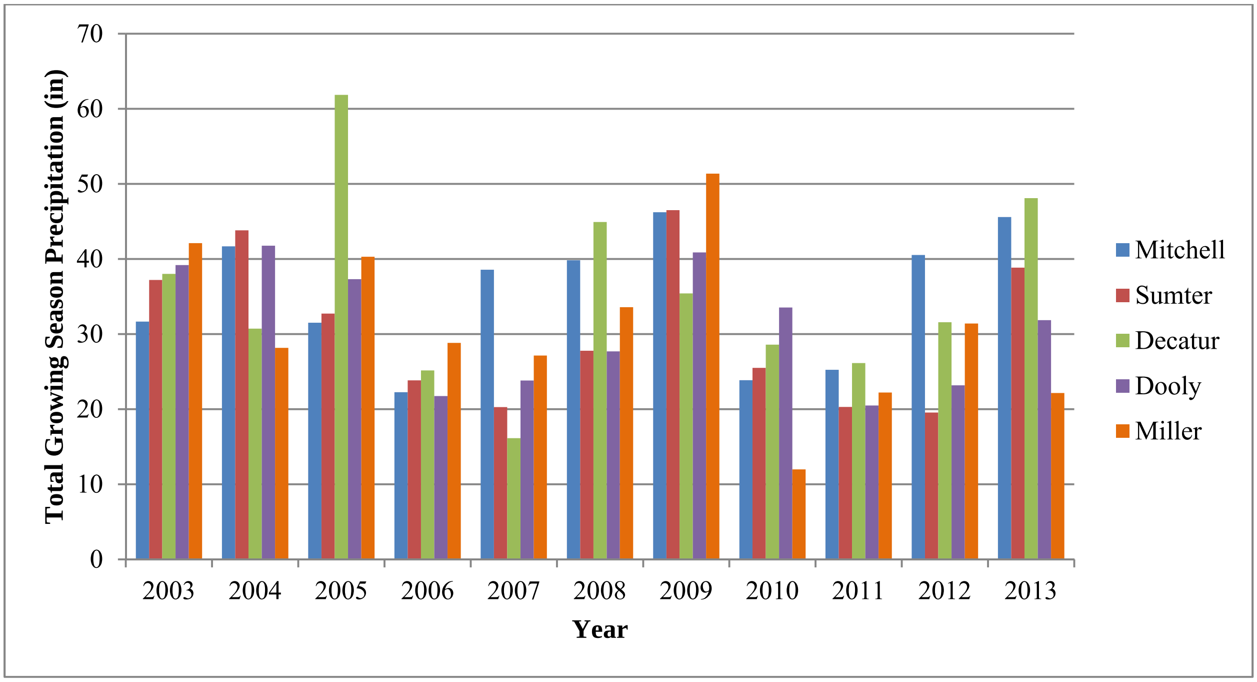
26. In addition to soil type, precipitation and climate conditions are other factors important to assessing the need for irrigation in ACF Georgia. As part of my work on this case, I calculated the daily vapor pressure deficit for several Georgia counties and analyzed precipitation data. I address both of these concepts below.

27. *First*, the daily vapor pressure deficit is a measure of the atmospheric demand for moisture from the surface or, in other words, how much water would evaporate from an agricultural field under the climatic conditions of a given day. I calculated daily vapor pressure deficit for Decatur, Dooly, Miller, Mitchell, and Sumter counties in Georgia. I calculated these values using the FAO56-Penman-Monteith (FAO56-PM) method. Experts in my field regularly use this method to calculate daily vapor pressure deficit. In ACF Georgia, summer can often be hot and dry. My calculations confirm that summer months are often the months of peak

atmospheric demand. All else being equal, under conditions of higher atmospheric demand, soils evaporate more water and thus hold less water for crops.

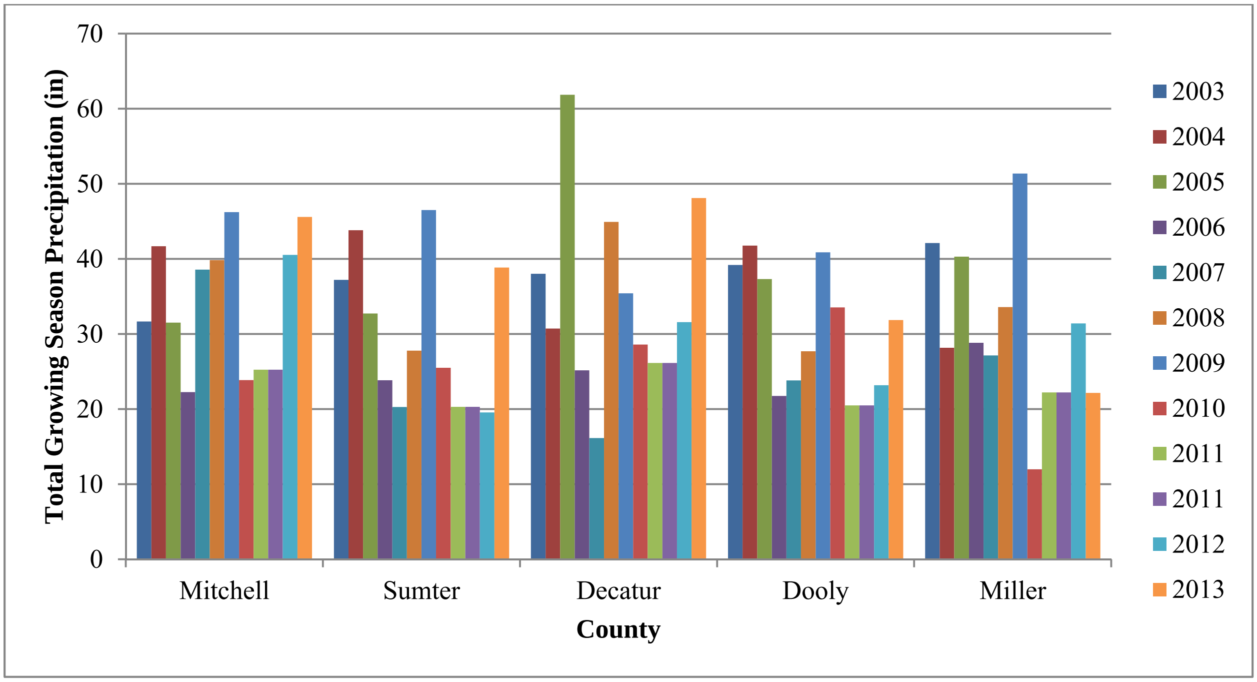
28. *Second*, I analyzed daily precipitation data for multiple sites in ACF Georgia collected by the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center. Experts in my field regularly rely on such government published data. That data shows that growing season precipitation patterns (precipitation from March through October) in ACF Georgia are highly variable, both from year to year and from county to county in the same year. During the growing season, rainfall can vary substantially on a day-to-day basis. For example, several days of rain can be followed by days or weeks of no rainfall. Irmak Demo. 1 and Irmak Demo. 2 graphically demonstrate this variability in precipitation that occurs in ACF Georgia. Irmak Demo. 1 shows county-to-county variations in growing season rainfall for different years. Irmak Demo. 2 shows year-to-year variations in growing season rainfall for different counties.

Irmak Demo. 1. County-to-County Variation in Growing Season Precipitation



Source: NOAA National Climate Data Center

Irmak Demo. 2. Year-to-Year Variation in Growing Season Precipitation



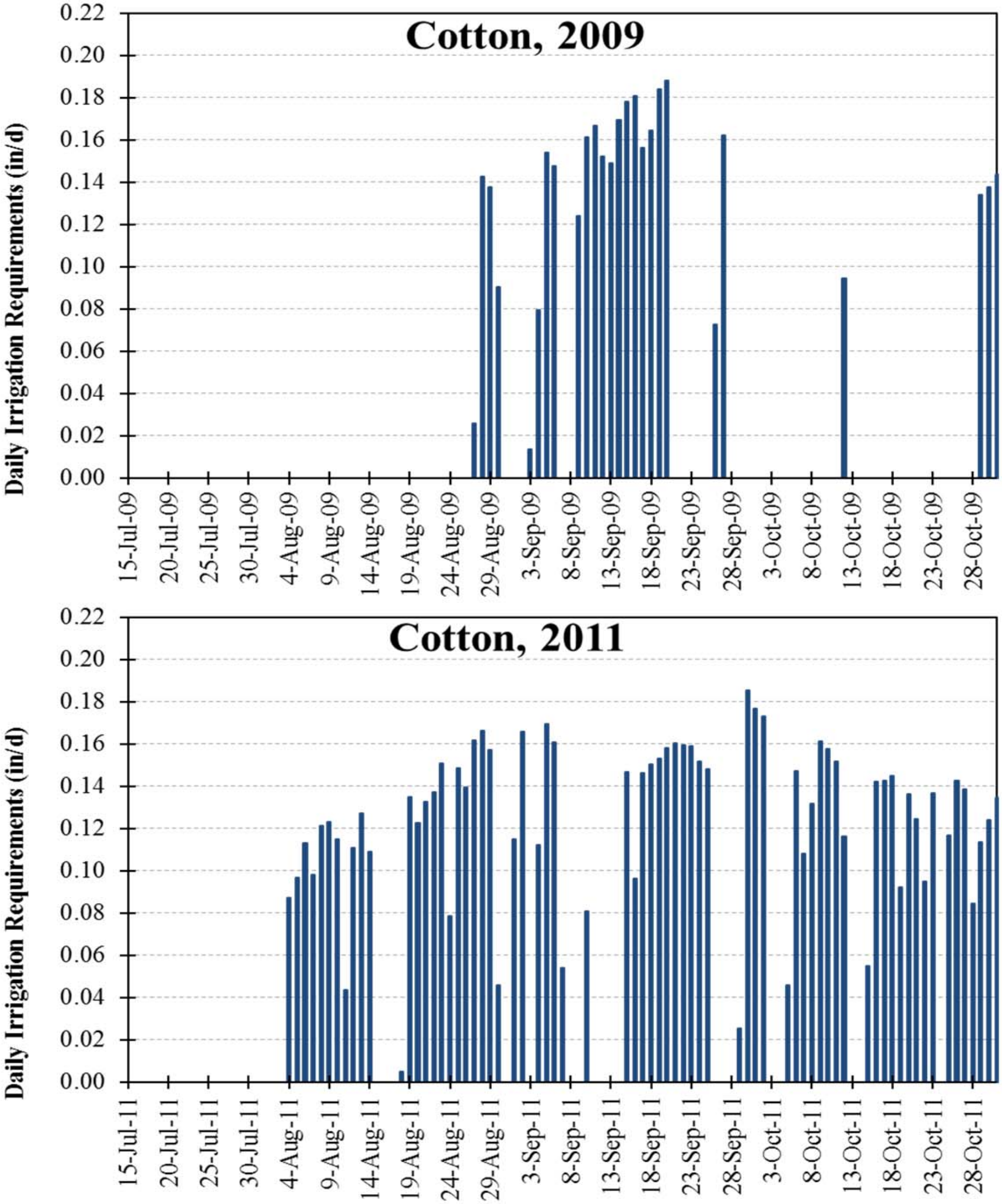
Source: NOAA National Climate Data Center

29. Even when precipitation events do occur, climatic conditions can still result in fast evaporation rates of soil moisture from sandy soils, particularly during the summer. In some cases, irrigation can be necessary even a day or two after precipitation events. The effect of high evaporative loss during summer months is even greater during drought years, when precipitation events occur less frequently. For those reasons, in the summer months, irrigation systems must be used frequently to ensure crop health, promote crop growth, and sustain profitability.

30. I calculated daily irrigation requirements for four major row crops in Georgia for five counties for at least eleven years. I explain how I performed these calculations in detail in Appendix 1. Irmak Demo. 3, Irmak Demo. 4, Irmak Demo. 5, and Irmak Demo. 6 show these daily irrigation requirements for Mitchell County in 2009 and 2011. I selected these two years because 2009 was a very wet year in Mitchell County and 2011 was a dry year. These charts show the net irrigation requirement, which does not account for irrigation application efficiency or management adjustments. They therefore understate the actual irrigation requirement for these crops. Nonetheless, they show that regardless of the overall levels of growing season precipitation, irrigation is necessary for period(s) of several consecutive days during the growing

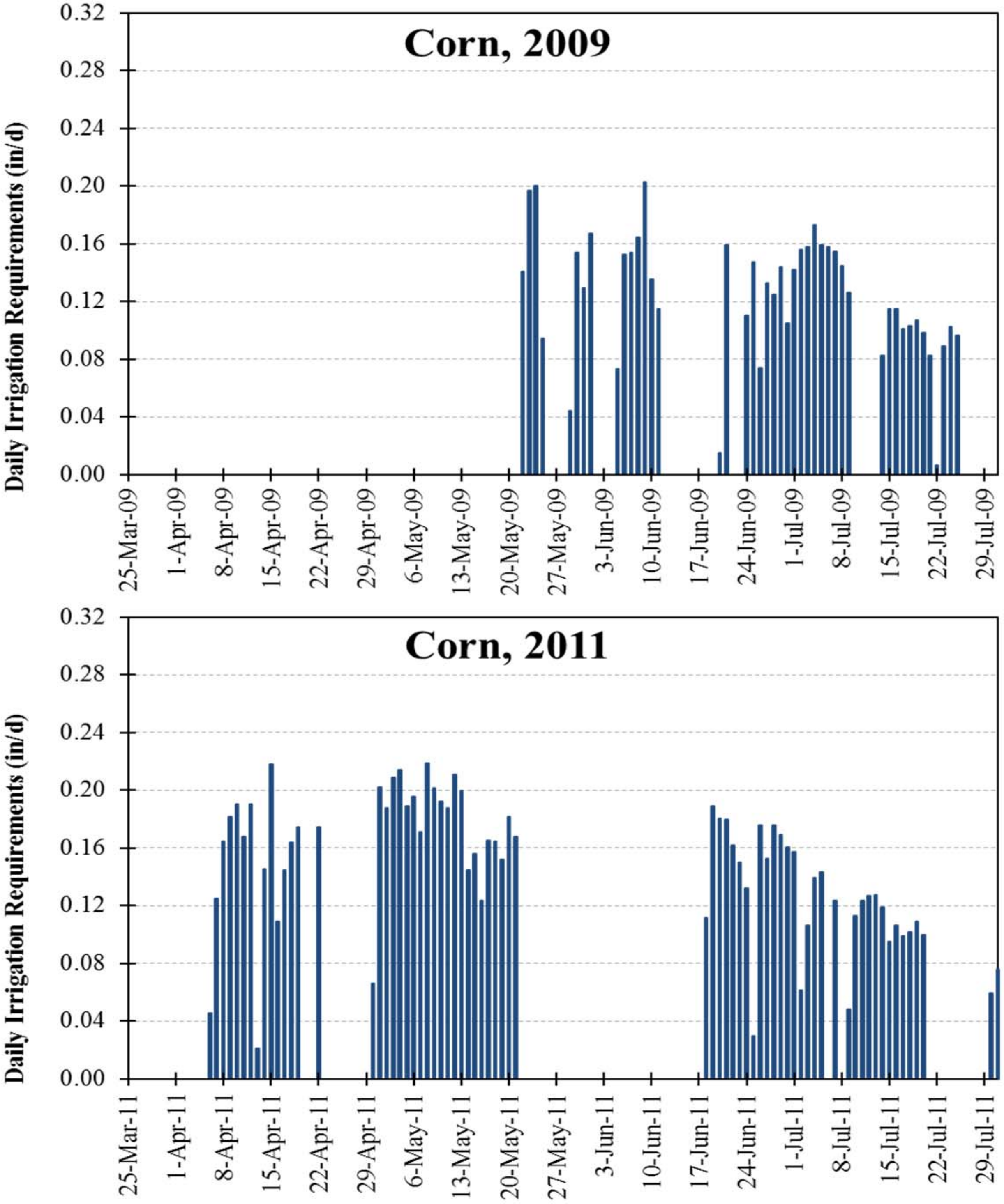
season. Failing to meet a crop's irrigation needs for several consecutive days exposes the crop to water stress, and continued stress can cause severe crop damage or even failure.

Irmak Demo. 3. Daily Cotton Irrigation Requirements in Mitchell County in 2009 & 2011



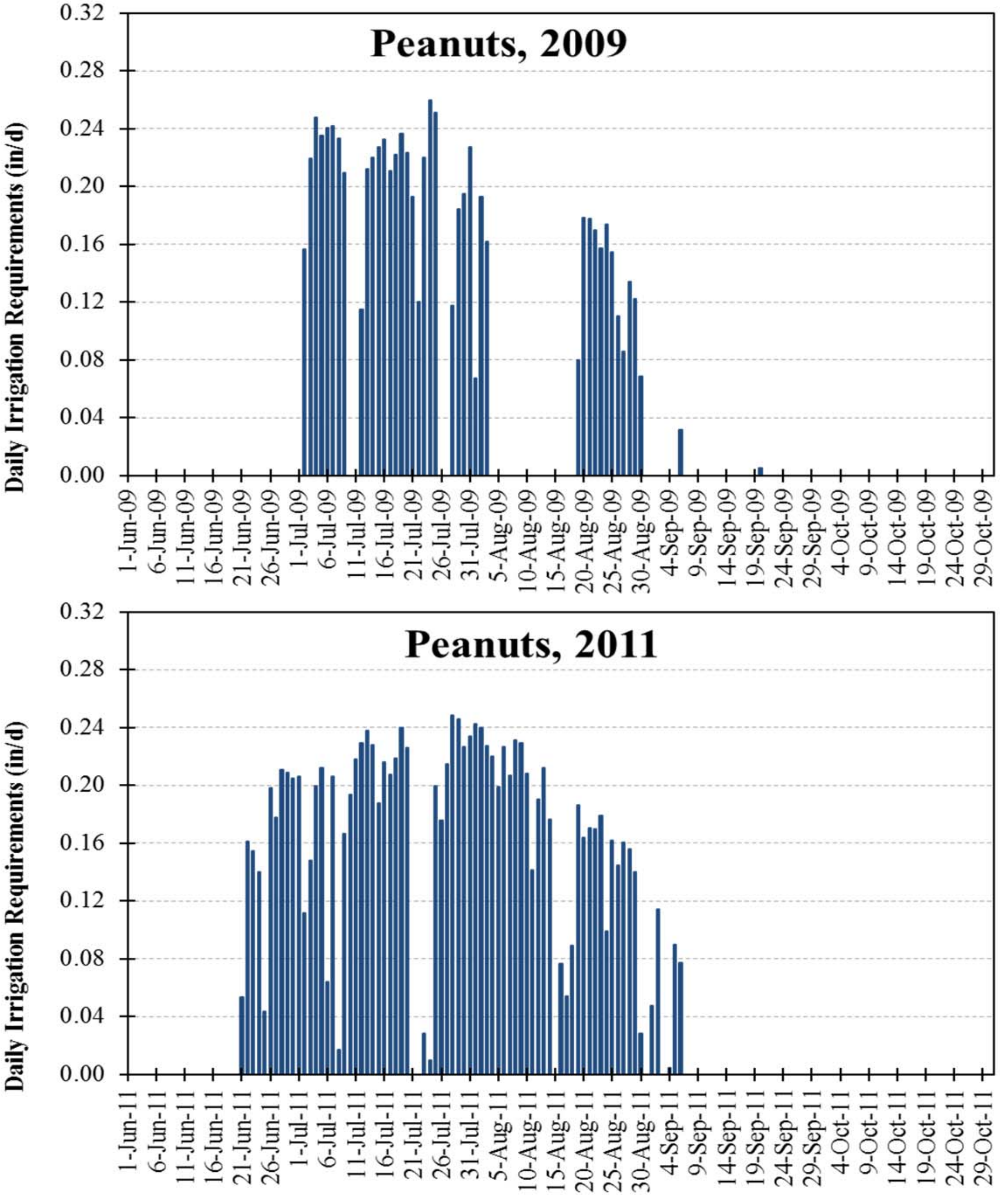
Source: ***See*** **Appendix 1**

Irmak Demo. 4. Daily Corn Irrigation Requirements in Mitchell County in 2009 & 2011



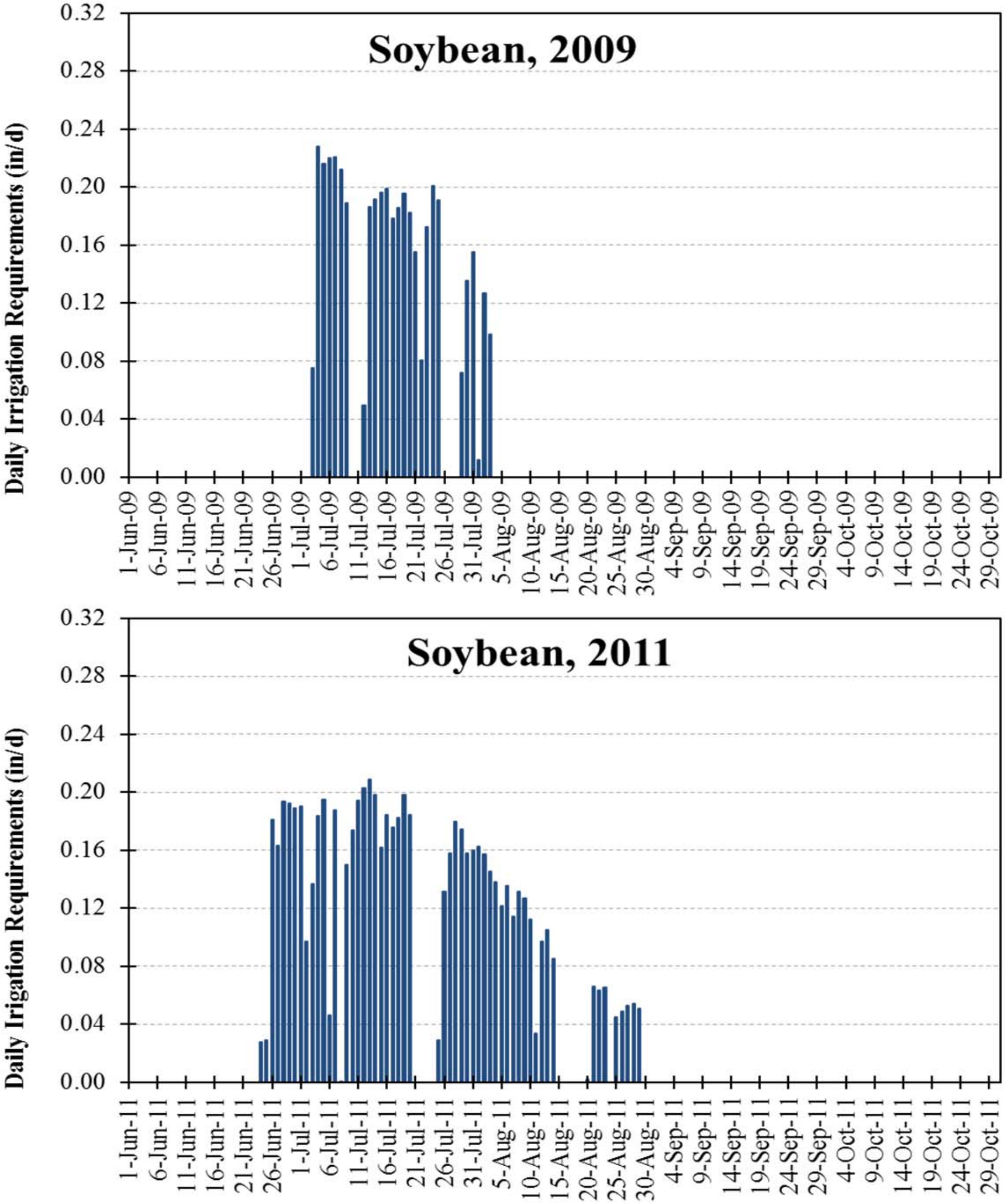
Source: ***See*** **Appendix 1**

Irmak Demo. 5. Daily Peanut Irrigation Requirements in Mitchell County in 2009 & 2011



Source: ***See*** **Appendix 1**

Irmak Demo. 6. Daily Soybean Irrigation Requirements in Mitchell County in 2009 & 2011



Source: ***See*** **Appendix 1**

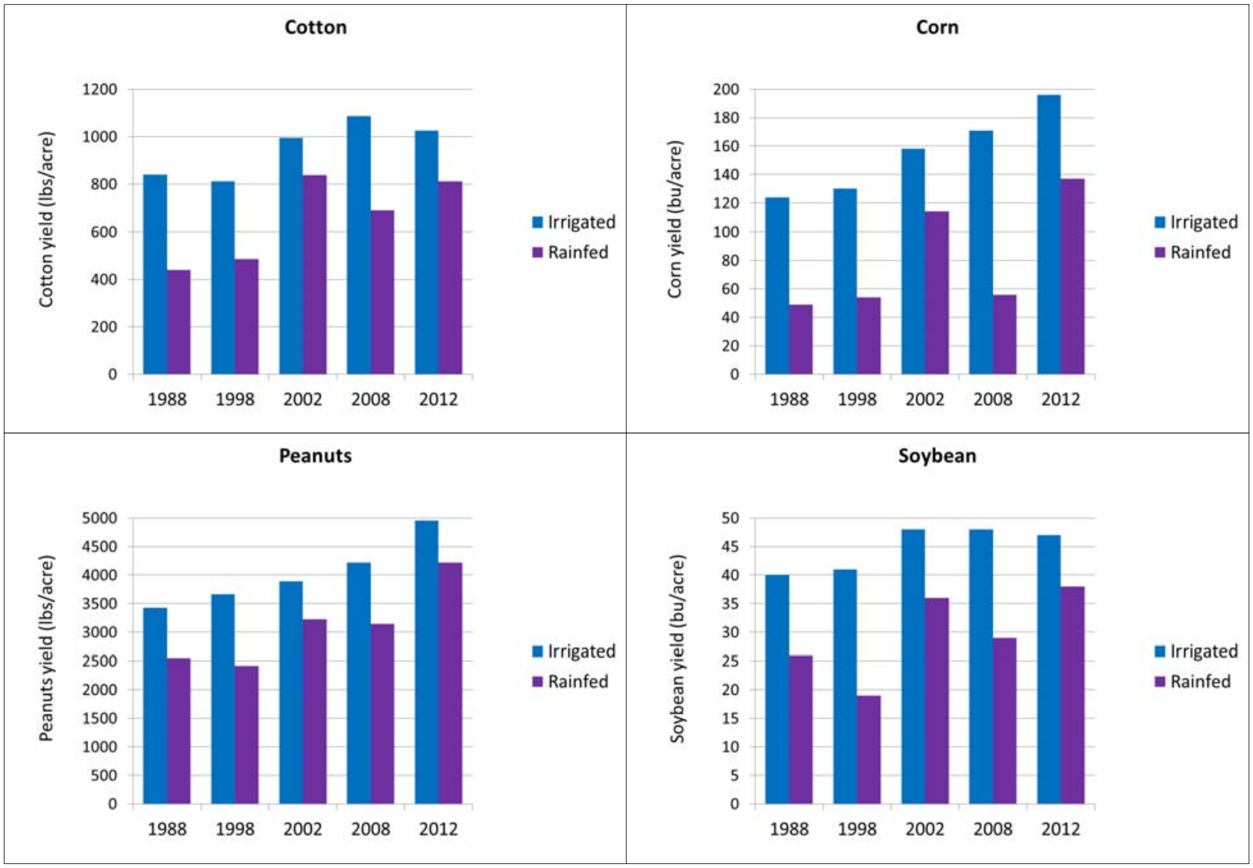
C. Irrigation v. Dryland Farming

31. As a result of these climate conditions and the low usable soil water of sandy soils in Southwest Georgia, irrigation of crops is necessary. Lack of precipitation for even a short period of time can impose extreme water stress on crops and can cause irreversible damage, either significantly reducing yield quantity and quality or resulting in complete crop failure. Irrigation is not a "discretionary" practice, but a practical requirement.

32. To demonstrate the critical importance of irrigation for crop yields, Irmak Demo. 7 below presents statewide average irrigated and non-irrigated yields in Georgia for 1988, 1998, 2002, 2008, and 2012 for four major crops (corn, peanuts, cotton, and soybean). GX-914, GX-915, GX-916, GX-917, GX-928 (USDA Farm and Ranch Irrigation Surveys). Without exception, irrigated yields substantially exceeded non-irrigated yields in all years. For example, for corn, irrigation increased yields over rainfed yields by over 116% on average and by over 200% in 2008.

- GX-914, GX-915, GX-916, GX-917, and GX-928 are true and accurate copies of the USDA Farm and Ranch Irrigation Surveys for 1988, 1998, 2002, 2008, and 2012. Experts in my field regularly rely on such data, and I reviewed this work in preparing my expert opinions.

Irmak Demo. 7. Irrigated vs. Rainfed Yields for Row Crops in Georgia



Source: GX-914, GX-915, GX-916, GX-917, GX-928 (USDA Farm and Ranch Irrigation Surveys)

33. Without irrigation, Georgia's agricultural productivity would suffer substantially, resulting in harm to the well-being of agricultural producers. Given the significant variability in precipitation and nature of the soils, dryland farming is a highly risky practice and not a realistic option for the majority of farmers in Southwest Georgia.

34. In his direct testimony, Dr. Sunding relies on USDA acreage data to suggest that switching from irrigated agriculture to rainfed agriculture is a feasible option for farmers in ACF Georgia. *See* Sunding Direct Testimony ¶¶ 22-23. This conclusion is incorrect for several reasons. Dr. Sunding focuses on only the total *crop acreage* that is irrigated or rainfed and not on the total *crop production* that comes from irrigated or rainfed fields. As I have shown above, irrigated fields have substantially greater yields than rainfed fields. Farm revenue, moreover, is primarily a function of crop yield rather than crop acreage. Switching from irrigated to rainfed agriculture could thus reduce farm revenue substantially, perhaps making it economically

infeasible for sustaining farming operations. Also, many farmers use a combination of irrigation and rainfed management on their fields. If those farmers can no longer irrigate (or can no longer irrigate to the same extent), that could potentially endanger the sustainability of the entire farm.

IV. GEORGIA IS A GOOD STEWARD OF AGRICULTURAL WATER RESOURCES

35. I was asked to evaluate the programs, policies, and initiatives undertaken by Georgia in the ACF Basin to manage agricultural water resources. I have extensive experience with such programs, from my work in Nebraska and elsewhere. Among other things, I served as an advisor to the state of Nebraska in reviewing integrated water management plans for natural resource districts in the state. In that capacity, I reviewed the proposed policy measures included in the plans and evaluated their impact on agricultural water use in Nebraska. I also have been involved with water policy measures in other states, and testified before Congress concerning water management and crop production challenges and the feasibility of having USDA develop programs to incentivize different agricultural management practices.

36. I reviewed hundreds of documents, including state laws and regulations, state and regional water planning reports and publications, and peer-reviewed literature. I also conducted on-site visits to the ACF Basin in Georgia and spoke to policymakers and stakeholders.

37. Based on that review, and based on my extensive experience in agricultural water management and policy, it is my opinion that Georgia has taken a reasonable, proactive, and conscientious approach to effectively managing its agricultural water resources.

38. During my deposition, counsel for Florida presented me with a number of documents from the late 1990s in which personnel from the Georgia Environmental Protection Division (“Georgia EPD”) expressed concern about the growth of agricultural irrigation and its potential impact on streamflows. Those documents do not change my opinion. Most of the programs and efforts that I have described occurred after the late 1990s, in direct response to those concerns. Implementing programs such as those described below is precisely how a responsible water manager should respond to water resource challenges. In particular, it is my opinion that the following programs and policies, when considered as a whole and as an overall

regulatory approach, demonstrate responsible management of agricultural water resources in light of water use challenges.

A. Permitting In The ACF Basin

39. In 1972, the Georgia Legislature established legal rules for managing and permitting of groundwater withdrawals and did the same for surface water withdrawals in 1977. In 1988, the Georgia Legislature adopted amendments to these statutes to incorporate withdrawals for agricultural use. Today, by law, any water withdrawals from any source exceeding 100,000 gallons per day must be granted a permit by Georgia EPD. *See* O.C.G.A§§ 12-5-31, 96 (2016).

40. In 1999, Georgia placed a moratorium on new agricultural groundwater withdrawal permits from the Floridan Aquifer in the Flint River Basin and on all agricultural surface water withdrawal permits for the Flint River Basin. JX-21 (2006 Plan).

41. The 1999 moratorium, and the associated planning process, lasted until 2006. From 1998 to 2006, Georgia conducted a multi-year Sound Science Study (described below) to develop a set of management recommendations to govern water use in the Flint River Basin. That process resulted in the adoption of the 2006 Flint River Basin Regional Water Development and Conservation Plan ("2006 Plan"), also described below.

42. In 2012, Georgia EPD instituted a new agricultural permit moratorium in additional portions of the Lower Flint and neighboring river Basins. The extended moratorium covered applications for groundwater withdrawals from the Floridan Aquifer in Subarea 4 (a USGS defined region where it considers pumping from the Floridan Aquifer to have an impact on streamflow), and applications for surface water pumping in the Spring Creek, Ichawaynochaway Creek, Kinchafoonee-Muckalee Creek, and Lower Flint River Sub-Basins. That moratorium remains in place today. JX-73 (2012 Moratorium).

B. Sound Science Study & The Flint Conservation Plan

43. In 1998, shortly before Georgia instituted the moratorium on new agricultural withdrawal permits, Georgia also initiated the Sound Science Study. The Sound Science Study was a comprehensive project designed to better understand and manage agricultural water

resources in the Flint River Basin. It involved compiling the best available data on water use, technical modeling of ground and surface water resources, developing information on stream ecology and flow regimes, and a thorough review of existing Georgia regulations relevant to water resource management. JX-21 (2006 Plan).

44. The Sound Science Study culminated in the 2006 Plan. The 2006 Plan contained numerous permitting recommendations and management practices. The Plan categorized the small watershed of the Flint River Basin into Capacity, Restricted, and Conservation Use Areas based on the modeled impact of groundwater pumping on streamflow in those watersheds. It also imposed restrictions on permitting including: (i) no new permits for fields solely in Capacity Use Areas, except for backlogged permits; (ii) conservation requirements, such as end gun shutoffs, leak maintenance, pump malfunction shutdown switches, and rain gage shutoffs; (iii) restrictions for groundwater permits based on proximity to other groundwater withdrawal sites or to streams affected by pumping; (iv) low flow protection plans for surface water permits that required irrigators to stop withdrawing water in certain low flow periods; (v) a system to revoke duplicative or inactive permits; and (vi) a new application fee. JX-21 (2006 Plan).

C. Comprehensive Statewide and Regional Water Planning

45. In 2004, the Georgia Legislature passed the Comprehensive Statewide Water Management Planning Act, which mandated the development of the Georgia Comprehensive Statewide Water Management Plan ("State Water Plan") so as to "manage water resources in a sustainable manner to support the state's economy, to protect public health and natural systems, and to enhance the quality of life for all citizens." O.C.G.A § 12-5-522(a). The State Water Plan was formally adopted in 2008.

46. Among other things, the State Water Plan established Regional Water Planning Councils ("Regional Councils") and required development of Regional Water Plans to help the State evaluate current and future water use, and conduct effective water planning. The regional water planning process involves engaging appointed stakeholder leaders in a cyclical process of water resource assessments and monitoring; forecasting needs for water demand and assimilative capacity; identifying management practices to meet needs and protect water resources; implementation and evaluation of management practices.

47. The first round of planning (2009–2011) involved a significant investment from the State of Georgia on data collection, modeling, resource assessments and regional council technical support. That process resulted in regional water plans being issued by the councils in the ACF Basin in Georgia. *See* FX-24 (Lower Flint Ochlockonee Regional Water Plan); GX-372 (Middle Chattahoochee Regional Water Plan); GX-1247 (Upper Flint Regional Plan). In 2015, the state began its initial five-year review and revision process, which will update these Regional Water Plans.

- FX-24, GX-372, and GX-1247 are true and accurate copies of the Regional Water Plans adopted by the Lower Flint Ochlockonee, Middle Chattahoochee, and Upper Flint Regional Water Councils in November 2011. Experts in my field regularly rely on such documents, and I reviewed them in preparing my expert opinions

D. Metering Program

48. In 2003, the Georgia General Assembly passed legislation to establish the Georgia Agricultural Water Use Measurement Program ("Agricultural Metering Program"), an effort designed to measure use of permitted agricultural water withdrawals statewide. Since 2004, Georgia has invested more than $22 million in deploying, maintaining and managing data collection on over 12,000 flowmeters statewide. *See* GX-1251 (Georgia Soil and Water Agricultural Water Metering Program Description).

- GX-1251 is a true and accurate copy of the Georgia Soil and Water description of its Agricultural Water Metering Program, which is publicly available at http://gaswcc.georgia.gov/metering-program. Experts in my field regularly rely on such information in evaluating agricultural water use, and I have reviewed this description in forming my expert opinions.

49. Initial flowmeter installations during 2004-2007 were concentrated on agricultural irrigation in Southwest Georgia. Irmak Demo. 8 shows the number of meters installed in southern Georgia by the end of 2009. By then, Georgia had a network of 6,985 meters, including 4,357 meters in (or near) the ACF Basin in Georgia to monitor agricultural withdrawals. JX-49 (USGS Report) at 3. The State has installed thousands more meters statewide since 2009.

Irmak Demo. 8. Water Meter Installations in Southern Georgia

Source	Meter Type	
	Annually Reported	Telemetry
Middle and Lower Chattahoochee and Flint River Basins		
Groundwater	3,609	46
Surface Water	748	35
Subtotal	4,357	81
Coastal Region		
Groundwater	679	20
Surface Water	378	16
Subtotal	1,057	36
Central South Georgia		
Groundwater	912	15
Surface Water	659	16
Subtotal	1,571	31
Grand total	**6,985**	**148**

Source: JX-49 (USGS Report) at 3.

50. The Georgia Soil and Water Conservation Commission ("Georgia Soil and Water") administers the Agricultural Metering Program and captures annual data on permitted withdrawals throughout Georgia. Meters are read each year between October 1 and December 31, and the readings are compared to the previous year's reading to provide the amount of water use generally corresponding to the growing season for most crops. At the time of reading, Georgia Soil and Water personnel or their contracted support staff also record the crop grown and perform a visual inspection of the meter. All meters receive a comprehensive inspection on a three-year rotating basis. Further, approximately 70-90 meters are read on a monthly basis as a sample to provide additional information on timing and use patterns during the growing season.

51. Having personally installed and maintained meters on my research farms, I know that installing a meter is a time and resource consuming process. For each meter, the entire irrigation system must be reviewed, a suitable meter location must be determined, the meter must be installed on the system or source, the meter must be tested and calibrated, and someone must periodically go to each meter to read it. Georgia's support for installing, maintaining, and reading a network of almost 12,000 meters represents a substantial investment by the State into gathering good data for improving its agricultural water use management.

E. Irrigated Acreage Mapping

52. Along with capturing data on agricultural withdrawals through the Metering Program, the State has invested in collecting data on the number of irrigated acres in the ACF Basin in Georgia. In prior years, the State contracted with Dr. Jim Hook from the University of Georgia to compile data on irrigated acreage in the ACF Basin and Georgia as a whole. Dr. Hook's efforts resulted in the creation of the NESPAL 2010 dataset, which was used for regional water planning efforts. JX-38 (NESPAL Agricultural Irrigation Water Demand Forecast Procedures). In more recent years, the State has contracted with the Georgia Water Planning and Policy Center at Albany State University ("Water Policy Center") to continue gathering data on irrigated acreage, which is ongoing today. While the Water Policy Center's work is statewide in scope, detailed assessments of irrigated acreage began in, and have largely focused, on the Flint River Basin. GX-84, GX-441, GX-807, GX-1241, GX-1242 (Water Policy Center contracts and amendments).

53. Since 2013, Water Policy Center personnel have visited and performed a detailed, in-field assessment of over 88% of the irrigated acreage in the lower Flint River region.[3] These assessments involve capturing precise withdrawal locations and source information, precise acreage irrigated by a particular source, acreage associated with each flowmeter, irrigation system type, installed conservation measures, and a series of other useful, site-specific information. The data collected as part of this mapping program was used to develop the latest version of the statewide database of irrigated acreage. JX-129 (2016 Wetted Acreage Database)

F. Flint River Drought Protection Act

54. In 2000, shortly after EPD imposed the 1999 moratorium, the Georgia Legislature passed the Flint River Drought Protection Act (FRDPA). The FRDPA gave the State of Georgia a mechanism to reduce irrigated acreage in the Flint River Basin during periods of severe drought, if the best available information indicated existing water use could result in unreasonable impacts to surface water flows in the Basin. Under the 2000 FRDPA, a "severe drought" declaration by the Director of Georgia EPD would trigger a series of steps including an

---

[3] Defined as the Lower Flint (HUC 03130008), Ichawaynochaway (HUC 03130009) and Spring Creek (HUC 03130010) Sub-basins.

auction to voluntarily remove land from irrigated production, in exchange for a per acre payment, for the balance of the calendar year. *See* O.C.G.A. § 12-5-546 (2000).

55. Following severe drought declarations by the Georgia EPD Director, an auction process resulted in retiring a total of 33,101 acres of irrigated land from production in 2001 and 40,894 acres in 2002. The State invested a total of approximately $10 million in the 2001 and 2002 auctions.

56. The Georgia General Assembly adopted several amendments to the FRDPA that refined Georgia EPD's abilities under the Act and established additional conservation mandates. The amendments accomplished the following: (i) gave EPD greater flexibility in deciding to implement the auction and in targeting specific watersheds; (ii) allowed EPD to include acreage irrigated by groundwater in the auction; (iii) required permittees to show that their land is actively irrigated to be eligible to participate in the auction; (iv) increased protection for flows augmented by State efforts; and (v) imposed new irrigation efficiency requirements of 80% for center pivot systems and 60% for solid set and mobile irrigation systems with staggered deadlines based on a permit's date of issue. *See* O.C.G.A. §§ 12-5-543, 544, 546, 546.1, 546.2 (2016).

57. Georgia has not implemented the FRDPA since 2002. It is not unusual for water planners to enact policy tools, implement those tools initially, and then later decline to implement those tools if the initial implementation proved ineffective or inefficient based on later collected data or later developed scientific information. Indeed, one would not expect policymakers to continue to implement policy tools that simply were not working, particularly tools that cost many millions of taxpayer dollars to deploy. In addition, the accurate prediction of drought (which the FRDPA requires) is a difficult task, and it is tough for Georgia to make that prediction by the Act's statutory deadline each year.[4] For those reasons, the fact that Georgia has not implemented the FRDPA since 2002 does not change my opinions in this case,

---

[4] The National Drought Mitigation Center recognizes this difficulty, explaining that a drought "is the result of many causes, often synergistic in nature" and can involve "air–sea interactions, soil moisture and land surface processes, topography, internal dynamics, and the accumulated influence of dynamically unstable synoptic weather systems at the global scale." Accordingly, "[s]cientists don't know how to predict a drought a month or more in advance for most locations." National Drought Mitigation Center, *Predicting Drought* (2016), available at http://drought.unl.edu/DroughtBasics/PredictingDrought.aspx.

especially given the other steps Georgia has taken to promote more efficient irrigation and conservation of agricultural water resources.

G. Center Pivot Adoption & Efficiency

58. Since the 1970s, Georgia irrigators have primarily utilized center pivot irrigation systems. Center-pivot irrigation is a method of irrigation in which the system rotates around a pivot point, usually set at the midpoint of the field, and crops are irrigated with impact sprinklers, low pressure sprinklers/emitters, or low pressure drop nozzles. Center pivots apply the irrigation water uniformly to the field with minimum surface runoff when designed and operated properly.

59. Based on my extensive experience in the field of agricultural irrigation, I know that center pivots are among the most efficient methods of irrigation in use today. Although no irrigation system can completely eliminate all non-productive water losses, center pivots apply water in relatively small increments, which ensures that more of the applied water reaches the crop root zone and significantly reduces non-productive water losses. When coupled with other water management programs, center pivot irrigation systems have proven to use water resources efficiently.

60. Even though center pivots themselves are among the most efficient irrigation methods, the State of Georgia and its farmers have made significant efforts to further improve the efficiency of these systems. Many of the center pivot irrigation systems adopted in Georgia during the 1970s and 1980s operated at high pressure (60 psi or greater), with sprinklers spraying water from the top of the pivot mainline. In contrast, low pressure spray sprinklers (operating between 10 to 30 psi) apply water in larger droplets, reducing water losses from wind drift and evaporation. Low pressure sprinklers on drop hoses apply water more closely to the crop canopy further reducing water losses. GX-1237 (Harrison, Extension Bulletin 882).

- GX-1237 is a true and accurate copy of a publication entitled Extension Bulletin 882, Factors to Consider in Selecting a Farm Irrigation System (2015), from the University of Georgia Cooperative Extension. It is publicly available at http://extension.uga.edu/publications/files/pdf/B%20882_4.PDF. Experts in my field regularly rely on such publications, and I reviewed this work in preparing my expert opinions.

61. In Georgia, many center pivots that previously used high-pressure impact sprinklers have been converted to more efficient low-pressure drop nozzles to further enhance the irrigation uniformity and efficiency of center pivot irrigation. Each retrofit requires removing and replacing up to over a hundred nozzles for each center pivot system.

62. USDA-NRCS data indicates that 1,065 center pivot irrigation systems in the region, representing 106,519 acres of irrigated land area, have been converted from high-pressure impact sprinklers to low-pressure drop nozzles using USDA-NRCS financial assistance from 2005-2014. Those numbers only include *conversions*, and do not include the number of systems that were *installed with* low-efficiency drop nozzles. Those numbers also do not include Georgia farmers who independently converted from high pressure sprinklers to low pressure systems without USDA-NRCS financial assistance. GX-1238 (Summary of USDA-NRCS Contracts).

- GX-1238 is a true and accurate copy of a document entitled Flint River Soil and Water Conservation District Summary of USDA-NRCS Contracts for EQIP and AWEP between 2005 and 2014. It includes data compiled by the Flint River Soil and Water Conservation District on the results of a USDA-NRCS grant implemented by the FRSWCD, which funded the conversion of center pivot irrigation systems from high-pressure to low-pressure sprinklers. Experts in my field regularly review such program and grant data, and I reviewed this work in preparing my expert opinions.

63. Data collected by the Water Policy Center also show that Georgia's efforts to convert center pivot systems in the State to low pressures systems have been successful. From 2013 through 2015, the Water Policy Center conducted detailed field mapping in large portions of the Lower Flint River Basin, including field mapping covering 100% of the Capacity and Restricted HUC 12 watersheds in that sub-basin. In the Lower Flint River Basin, the vast majority of systems are now operating with high efficiency sprinklers. The Center's data shows that nearly 90% of the center pivots in the Lower Flint River Basin employ low pressure sprinklers or low pressure drop nozzle technology, covering approximately 93% of the irrigated acreage in those areas. GX-1133 (LF Mapping), JX-141 (GWPPC Mapped Pivots_Flint

Basin.xlsx). Low-pressure, drop-nozzle center pivots are some of the most efficient center pivot systems on the market today. Such systems can achieve efficiency levels of 80% or greater.[5]

H. Mobile Irrigation Laboratory

64. In addition to retrofitting hardware to improve center pivot efficiency, Georgia has invested in improving center pivots through its Mobile Irrigation Laboratory ("MIL").

65. The MIL is provided at no cost to farmers. Upon request from an irrigator, Georgia MIL technicians visit a field and test and retrofit (when possible) the irrigation system for uniformity and efficiency. MIL technicians evaluate both the sprinklers on the center pivot spans and the end-gun that farmers sometimes install on the last tower of the center pivot to increase irrigated area. For the sprinklers, technicians work to improve uniformity of water distribution, which leads to higher efficiency. For the end-guns, technicians sometimes install end-gun shut-off devices that stop the gun from operating in certain portions of the field. These efforts improve the efficiency of irrigation systems and can reduce agricultural water use.

66. Over 560 center pivot systems have been serviced and/or retrofitted by the MIL, including many center pivot irrigation systems in the Lower Flint River Basin, to address and improve uniformity, which increases irrigation efficiency. Over 50,000 irrigated acres have been tested by MILs in Georgia. GX-1239 (Georgia Soil and Water, *Mobile Irrigation Lab*). As of 2010, the State had invested nearly $3 million in the Mobile Irrigation Lab program. GX-1126 (Georgia Soil and Water, *Agricultural Water Conservation Initiative Program Data*).

- GX-1239 is a true and accurate copy of a publication from Georgia Soil and Water entitled Georgia Agricultural Water Conservation Initiative, Mobile Irrigation Lab. Experts in my field generally rely on such data to evaluate agricultural water use, and I reviewed and relied upon this data in formulating my opinions.
- GX-1126 is a true and accurate copy of a publication from Georgia Soil and Water entitled Agricultural Water Conservation Initiative Program Data. Experts in my field generally rely on such data to evaluate agricultural water conservation programs, and I reviewed and relied upon this data in formulating my opinions.

---

[5] *See* Irmak, et al., *Irrigation Efficiency and Uniformity, and Crop Water Use Efficiency*, Biological Systems Engineering: Papers and Publications, Paper 451 (2011) at 3.

67. Before and after each retrofit of a center pivot system, MIL personnel conduct uniformity and operational tests to quantify the improvements in uniformity and efficiency due to the retrofit performed by the MIL. I obtained the testing results of about 250 retrofits from the Georgia Soil and Water Conservation Commission. The results of these tests show that before MIL improvements, center pivots had an average uniformity of 73.5%. After the retrofit/improvements, the uniformity of the center pivots improved substantially, ranging from 81% to 88% with an overall average of 85%. JX-140 (GA MIL Data.xlsx).

68. I also obtained data on the actual water savings due to uniformity/efficiency improvements and installation of end-gun shutoff devices through the MIL, which have been measured by Georgia Soil and Water. The total water savings due to uniformity and efficiency improvements as a result of MIL's substantial efforts was 965.7 million gallons per growing season. The total water savings due to installing end gun shut-off devices was 232 million gallons per growing season. Again, these numbers are only for a single growing season in a single year. JX-140 (GA MIL Data.xlsx), *see also* GX-908 (Flint River Basin Irrigation Performance Evaluation Report).

- GX-908 contains the results of a mobile irrigation lab audit. Experts in my field regularly rely on such data to evaluate agricultural water use conservation programs, and I reviewed and relied upon this data in formulating my opinions.

I. Conservation Tillage

69. Georgia has also researched and encouraged farmers to adopt conservation tillage, where appropriate, through its state university research and extension programs. Conservation tillage is a water-saving irrigation practice that involves using a cover crop and intentionally leaving plant residue from a prior crop to cover at least 30% of the soil surface of the field. Reduced tillage involved leaving plant residue from a prior crop to cover 15-30% of the soil surface of the field. This modifies plant rooting structure to enable more efficient water use by crops, and it improves the water holding capacity of the soil by increasing its organic matter content. In general, water infiltration rates increase, and soil temperature, evaporative loss, and field runoff decrease. Converting from conventional tillage to conservation tillage can reduce water use by up to 15% or more, depending on soil and water management practices, climate, irrigation method and other factors. By 2004, Georgia had adopted conservation or reduced

tillage on over 46% of all crops, and for about 53% of cotton, 45% of corn, and 69% of soybean grown in the state. GX-58 (Conservation Technology Information Center, *2004 National Crop Residue Management Survey*). In addition, at their Hooks-Hanner Environmental Resource Center, Georgia Soil and Water cooperates directly in research on irrigation and water management strategies on conservation tillage via a cooperative agreement with the USDA.

- GX-58 is a true and accurate copy of a publication from from the Conservation Technology Information Center entitled 2004 National Crop Residue Management Survey (2004). It contains information about the level of conservation tillage in several states, including Georgia, as of 2004. Experts in my field regularly rely on such publications, and I reviewed this work in preparing my expert opinions.

J. State Supported Institutions

70. The State of Georgia has also funded a number of institutions and research facilities that help improve agricultural water use efficiency and make resources available to farmers.

71. The Flint River Soil and Water Conservation District supports stewardship and conservation of soil and water. The Flint District covers most of the Lower Flint River Basin. It has applied for and manages multiple competitive state and national grants promoting conservation efforts, including the adoption of advanced irrigation technology. Together, those improved conservation practices cover more than 200,000 acres of irrigated acreage in the Lower Flint River Basin. The Flint District also works with private groups to educate farmers on best irrigation practices and conservation opportunities.[6]

72. The University of Georgia's Stripling Irrigation Research Park is a state-of-the-art irrigation research and education center located in the Lower Flint River Basin. UGA Stripling collaborates with other universities and state and federal agencies to research improving irrigation systems and practices for better soil and water conservation and management. It has conducted research into a variety of crops, including cotton, corn, peanut, tomatoes, sweet corn,

---

[6] *See* Flint River Soil and Water Conservation District, *Projects*, available at http://flintriverswcd.org/projects/. To gather information on the Flint District, I spoke with Casey Cox, Executive Director of the Flint River Soil and Water Conservation District.

and soybeans.[7] Stripling has around 75 acres of research plots, which scientists and engineers use to find new ways to more efficiently apply irrigation water. It routinely disseminates and makes available the research and results to the farmers to help them improve agricultural management and farming practices.

73. The University of Georgia Cooperative Extension conducts education and outreach with farmers to encourage the adoption of irrigation and agricultural management best practices. Its efforts include issuing circulars and publications directed towards farmers and holding workshops, field days, and seminars to directly reach farmers. UGA Extension has held face to face workshops in 151 counties in Georgia and had over 260,000 face to face contacts from these efforts. GX-1240 (Risse, et al., *Georgia's Water Conservation Efforts: Cooperative Extension's Banner Effort*).

- GX-1240 is a publication by L. Mark Risse, et al., from the 2009 Georgia Water Resources Conference entitled Georgia's Water Conservation Efforts: Cooperative Extension's Banner Effort. It details some of the water conservation efforts that have been undertaken by the Universty of Georgia Extension. Experts in my field regularly rely on such publications, and I have reviewed this publication in preparing my expert opinions

74. The Georgia Water Planning and Policy Center at Albany State University conducts mapping efforts and provides other technical support to the State and to Regional Water Councils in their water planning efforts. It also conducts its own outreach and extension work to encourage the adoption of better irrigation practices.[8]

V. GEORGIA'S ESTIMATION OF TOTAL AGRICULTURAL WATER USE IS BASED ON RELIABLE METHODOLOGIES AND DATA

75. I was also asked to evaluate the methodologies used by the State of Georgia to estimate total agricultural water use in the ACF Basin and to offer an opinion on the reliability and validity of these methods. To evaluate Georgia's methods, I spoke with State officials from the Georgia Environmental Protection Division and reviewed the data files and the step by step

---

[7] *See* University of Georgia, *C.M. Stripling Irrigation Research Park Background*, available at http://striplingpark.org/background/. To gather information on the Stripling Irrigation Research Park, I spoke with Calvin Perry, Superintendent of the Park.

[8] *See* Georgia Water Planning and Policy Center, available at http://www.h2opolicycenter.org/aboutus.html. To gather information on the Water Policy Center, I spoke with Mark Masters, the Director of the Center.

methodology that the State used to calculate irrigated acreage, irrigation depths, and total agricultural water use in the ACF Basin. I also analyzed the methodologies used by experts for the State of Florida.

76. I conclude that Georgia's approach, which is based on over a decade of data collection and analysis and was put together as part of the state's comprehensive state water planning process, is based on sound scientific methods and is reliable. In my opinion, Florida's estimates overstate total agricultural water use in Georgia's ACF Basin in several respects

A. Estimating Agricultural Water Use

77. Agricultural water use in Georgia's ACF Basin consists primarily of water withdrawn for irrigation of crops. Water used for crop irrigation is withdrawn from surface water sources and from groundwater wells, which tap into the productive and accessible Floridan Aquifer. Georgia irrigators also withdraw water from deeper aquifers, including the Clayton, Claiborne, and Cretaceous aquifers.

78. Agricultural withdrawals are best estimated by multiplying (1) the total number of irrigated acres from relevant sources by (2) irrigation "application depths," or the volume of water pumped from irrigation systems. Total agricultural withdrawals are calculated by multiplying these two values. Because many of these agricultural withdrawals are from groundwater sources, additional calculations must be made to determine the impact these withdrawals might have on streamflows.

B. Opinions Regarding Georgia's Methodology

79. The below includes a brief overview of the methodology used by Georgia EPD to estimate agricultural water use. Since the late 1990s, Georgia has contracted with several entities to collect data on irrigated acreage in the ACF Basin and in other portions of the state. By 2004, the first extensive Geographic Information System (GIS) layer of irrigated acreage across the Flint River Basin had been completed. This GIS layer served as the basis for technical analyses supporting the 2006 Plan.

80. In 2009-2010, as part of Georgia's Statewide Water Planning Process, this GIS layer was expanded to cover the entire state, including the Georgia portion of the ACF River

Basin. This 2010 irrigated acreage database was compiled by the National Environmentally Sound Production Agricultural Laboratory (NESPAL) at the University of Georgia. I refer to this database as the "2010 NESPAL Database." GX-920 (2010.0416 Map_Fields_in_LDAs). In 2013, another round of field mapping was launched which, by 2015, had captured detailed information on over 88% of the irrigated acreage in the Lower Flint River Basin. This mapping effort was conducted by the Water Policy Center, and I refer to this data as the "2016 Wetted Acreage Database." JX-129 (2016 Wetted Acreage Database). As of today, wetted acreage data exists reflecting total wetted acreage in Georgia's ACF Basin from 2004 to 2014.

- GX-920 is a true and accurate copy of the publicly available irrigated acreage data compiled by NESPAL into the 2010 NESPAL Database. Experts in my field regularly rely on such data in evaluating agricultural water use, and I have reviewed this database in forming my expert opinions.

81. The Direct Testimony of Wei Zeng, Ph.D. contains a detailed discussion of Georgia EPD's methodology for calculating irrigated acreage. I have reviewed this methodology carefully, and I find it to be an accurate and reliable way to calculate irrigated acreage in the Georgia portion of the ACF Basin. Georgia EPD divided and estimated irrigated acreage by the type of water source: surface water, groundwater, and well-to-pond (which involves pumping water from an underground aquifer to a surface pond and then pumping from the pond to the field for irrigation). Georgia EPD then further attributed the well-to-pond acreage into surface water and groundwater acreage. I understand that withdrawals from non-Floridan aquifer sources have minimal impacts on streamflow. Accordingly, for some years Georgia focused only on acreage irrigated from the Florida aquifer. In other years, Georgia calculated acreage irrigated from the Floridan aquifer separately from acreage irrigated from other aquifers. Irmak Demo. 9 presents irrigated acreage in ACF Georgia as calculated by Georgia EPD.

Irmak Demo. 9. Total Irrigated Acres in ACF Georgia

Year of mapping of irrigated acreage	Time periods of irrigated acreage applied	Surface water-irrigated acres	Groundwater-irrigated (Floridan /Aquifer) acres	Groundwater-irrigated (non-Floridan Aquifer) acres	Total irrigated acres
2004	2001-2004	196,001	403,219		
2009	2005-2007	166,781	378,875		
2010	2008-2012	172,640	409,876	110,826	693,342
2013	2013	161,080	424,716	126,822	712,618
2014	2014	132,311	436,114	154,702	723,127

Source: Georgia EPD

82. To calculate irrigated acreage before 2004, EPD created a trend line of total irrigated acreage in the state from 1970-2013 using pre-2000 survey data compiled by the University of Georgia Extension. This is a reasonable method of estimating statewide irrigated acreage for years in which reported data is not available. This trendline of statewide irrigated acreage was used to estimate historical irrigated acreage in ACF Georgia by assuming that the proportion of irrigated acreage in ACF Georgia, as compared to the whole state, remained consistent from 1970-2004. Given the data limitations before 2004 and inherent uncertainty involved in estimating historical information, the State's method is reasonable.

83. Regarding application depths, there are essentially two methods used by EPD to estimate irrigation application depths: (i) irrigation application depths based on data from the Agricultural Metering Program (2008-present); and (ii) irrigation application depths based on a study by Dr. James Hook from NEPAL (pre-2008). JX-35 (Memo from Wei Zeng, *Memo re Agricultural Water Use and its Surface Effects in the Flint and Lower Chattahoochee River Basins* (April 2, 2009)).

84. Since 2008, Georgia EPD has had access to annual readings from the entire population of flowmeters installed on agricultural irrigation systems throughout the state, including the ACF Basin, as part of Georgia's Agricultural Metering Program. The annual meter readings in the Agricultural Metering Database reflect approximately 70-80% of irrigation systems in the ACF Basin. In addition to annual readings, approximately 70-90 systems have been monitored and read at monthly intervals since 2012. The monthly reading sites provide

average monthly water use patterns and are used to represent intra-annual application patterns of irrigation systems throughout the state.

85. From 2002 to 2007, Georgia used recorded monthly application depths as reported by a study conducted by Dr. James Hook from NESPAL. Dr. Hook's study involved monitoring and collecting data on a sample of over 200 irrigation systems in the Flint River Basin over the period 1998-2003. Dry-year and normal-year application depths were estimated according to Dr. Hook's HUC-8 application data. These years were categorized as dry (2002, 2006, and 2007) and normal (2003, 2004, and 2005). Following this categorization, intra-annual distributions of irrigation application depth were estimated for both dry and normal years prior to 2008. JX-17 (James E. Hook, et al., *Ag Water Pumping Project Report 52* (2005)) at 3.

86. Using the above-described acreage data and application-depth data, Georgia EPD has calculated agricultural withdrawals in the Georgia portion of the ACF Basin. Based on my review of the data sources and EPD's methodology, I find EPD's calculations to be scientific and reliable.

C. Opinions Regarding Florida's Methodology

87. I have reviewed Florida's estimates of agricultural water use in Georgia's ACF Basin as reported by Dr. Sunding in his written direct testimony. In my opinion, those estimates suffer from certain flaws that lead Florida to overstate the amount of agricultural water use in ACF Georgia. *First*, when Florida's experts calculated agricultural withdrawals during discovery in this case, they confused "hardware" and "throw" acres, which led them to overstate agricultural withdrawals. In his written direct testimony, Dr. Sunding purports to fix that error, but it is unclear whether they have in fact done so. *Second*, Florida's estimates are overstated because they include acres irrigated from deeper aquifers in their irrigated acreage estimates, which overstates the total irrigated acreage that has a streamflow effect.

1. "Hardware" and "Throw" Acres

88. "Hardware acres" and "throw acres" refer to two different methods for estimating the acreage irrigated by a particular center pivot system. Most center pivot irrigation systems apply water in two ways. First, center pivots have sprinklers directly under or on top of the

spans of the pivot (called the center pivot hardware). The acreage irrigated by just these sprinklers is called "hardware acres." Second, many center pivots have a single, larger sprinkler at the end of the spans, called end-guns, that throw water past the end of the center pivot hardware. The acreage irrigated by these end guns is called "end gun acres." "Throw acres" refers to the acreage under the center pivot system hardware *plus* estimated acreage irrigated with an end-gun throw.

89. When calculating agricultural water use for any given year, it is important to be consistent with respect to using hardware acres only or throw acres only. You can use either to accurately calculate water use, but you have to be consistent in the way you do it. For example, if you use hardware acres to calculate irrigation depths, then those irrigation depths must be multiplied by hardware acres only. Alternatively, if you use throw acres to calculate irrigation depths, then those irrigation depths must be multiplied by throw acres only. If you mix up the two—for example, multiplying hardware based irrigation depths with a throw acre value for irrigated acreage—then agricultural consumptive use will be incorrect.

90. Florida made this basic error in the agricultural consumptive use estimates it produced to Georgia in discovery. In their expert reports, Dr. Sunding and Dr. Flewelling multiplied hardware-based irrigation depths with a throw acre value for total irrigated acreage to estimate total water use. This led to Florida overstating total water use in ACF Georgia. For example, Dr. Sunding overstated agricultural consumptive use by approximately 65,000 acre-feet in dry years and 53,000 acre-feet in average years, an inflation of 11.9% in dry years and 11.6% in average years. In his written direct testimony, Dr. Sunding concedes that he made this error. *See* Pre-Filed Direct Testimony of Dr. David Sunding at ¶ 96. He attempts to correct for this mistake by "divid[ing] the reported volume of water usage by 1.1 times the reported irrigated acreage." But it appears that Dr. Sunding has made additional changes to his assumptions in order to keep his drought year irrigation depths artificially high. Correcting for his mistake regarding hardware and throw acres should have led Dr. Sunding to use *lower* irrigation depths.

However, he now uses an irrigation depth for drought years that is 1 inch greater than the dry-year irrigation depth he calculated in his expert report.[9]

2. Florida Overstates Streamflow Impacts by Including Acreage Irrigated from Deeper Aquifers

91. Florida's experts also inflate total groundwater-irrigated acreage because they fail to distinguish between acreage irrigated from the Floridan Aquifer and acreage irrigated from deeper aquifers that have a lower degree of hydrologic connectivity to surface water resources. Although it is true that groundwater pumping from those deeper aquifers removes water from the aquifer, I understand that those aquifers have no substantial connection to surface water, and thus do not materially reduce surface streamflow.

92. As of 2014, roughly 436,000 acres in the ACF Basin were irrigated from the Floridan Aquifer, 132,000 acres were irrigated from surface water, and 154,000 acres were irrigated from non-UFA aquifers. By including acres that are irrigated from non-Florida Aquifer sources in their estimates, Florida's experts contribute to an inflated estimate of the amount of agricultural water use that could potentially affect streamflow in the ACF Basin.

VI. OPINIONS REGARDING THE CALCULATION OF CROP WATER USE EFFICIENCY IN THE ACF BASIN IN GEORGIA

A. Findings Regarding Crop Water Use Efficiency in Georgia

93. I was also asked to assess the levels at which Georgia farmers are irrigating in ACF Georgia. To do this, I used a scientifically well-accepted methodology to calculate the amount of irrigation that crops in the Georgia portion of the ACF Basin required in prior years under various climatic conditions. I then compared those irrigation requirements to the amount of water that Georgia farmers actually applied during those time periods, as measured by agricultural water meters. A detailed description of my methodology and processes is attached as Appendix 1 to my testimony. Note that my calculations below differ somewhat from those previously reported in my expert report, as a result of questions raised by Florida during my deposition. The relevant changes are explained in Appendix 1. In most cases, I show that, even

---

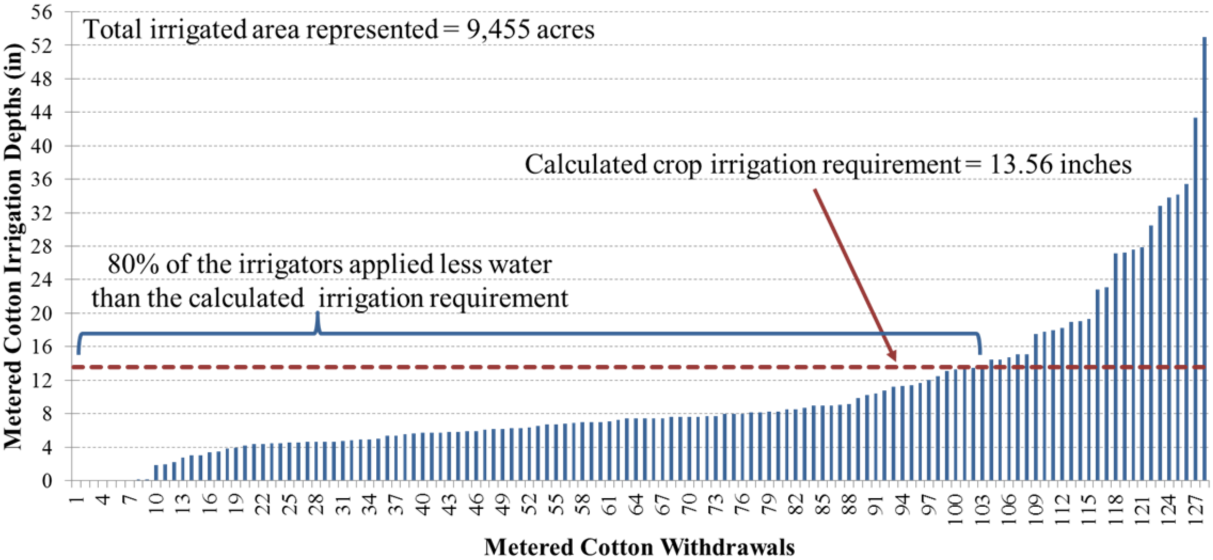
[9] Florida recently provided additional materials that Dr. Sunding relied on in support of his new opinions. Given the limited time I have had to review this new material, I reserve my right to supplement or modify my testimony related to this topic after I have had more time to review.

accepting Florida's position on certain assumptions underlying my calculations, Georgia farmers are still (in the aggregate) applying water efficiently.

94. Using flowmeter data provided by the State, I calculated the percentage of farmers using less than the crop irrigation requirement for 2011, to evaluate farmer efficiency during a drought year, as long as there were at least eight farmers with metered data in the county growing that crop. If there were not enough farmers growing that crop, I calculated the percentage of farmers using less than the crop irrigation requirements for that county in 2012. Irmak Demo. 10, Irmak Demo. 11, and Irmak Demo. 12 show the number of farmers in Miller County, Georgia irrigating below the crop requirements for corn, cotton and peanuts in 2012. GX-922, GX-923, GX-926, GX-927 (2011 and 2012 Flowmeter Data).

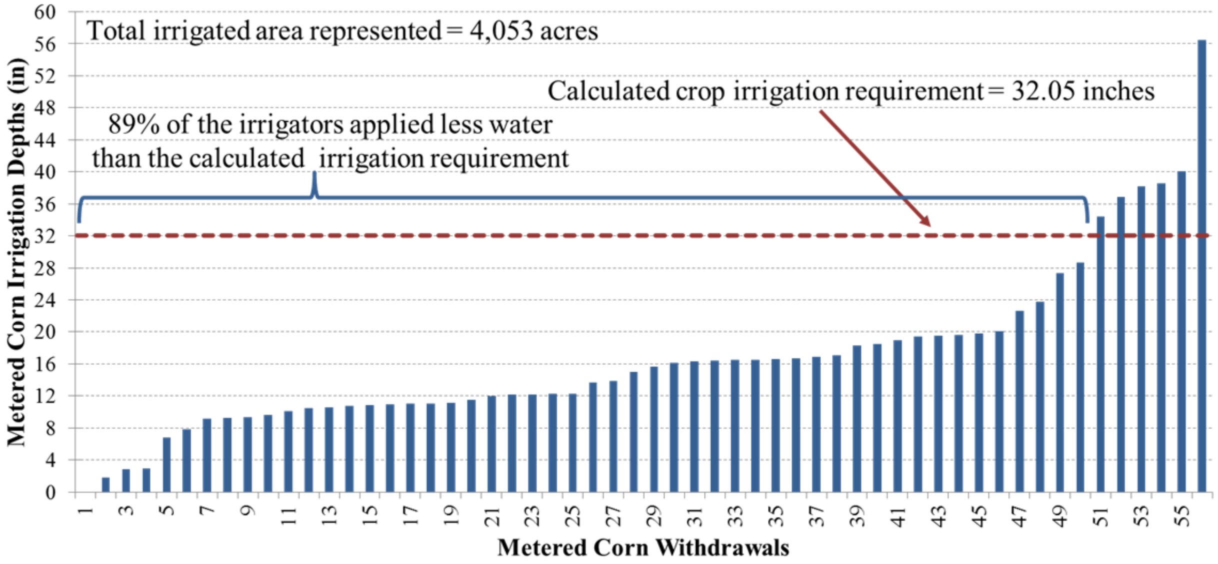
- GX-922, GX-923, GX-926, and GX-927 are true and accurate copies of flowmeter data provided by the State of Georgia. Experts in my field regularly rely on such data in evaluating agricultural water use, and I have reviewed this data in forming my expert opinions.

Irmak Demo. 10. Percentage of Metered Cotton Farmers Irrigating Below Cotton Irrigation Requirements in Miller County, 2012



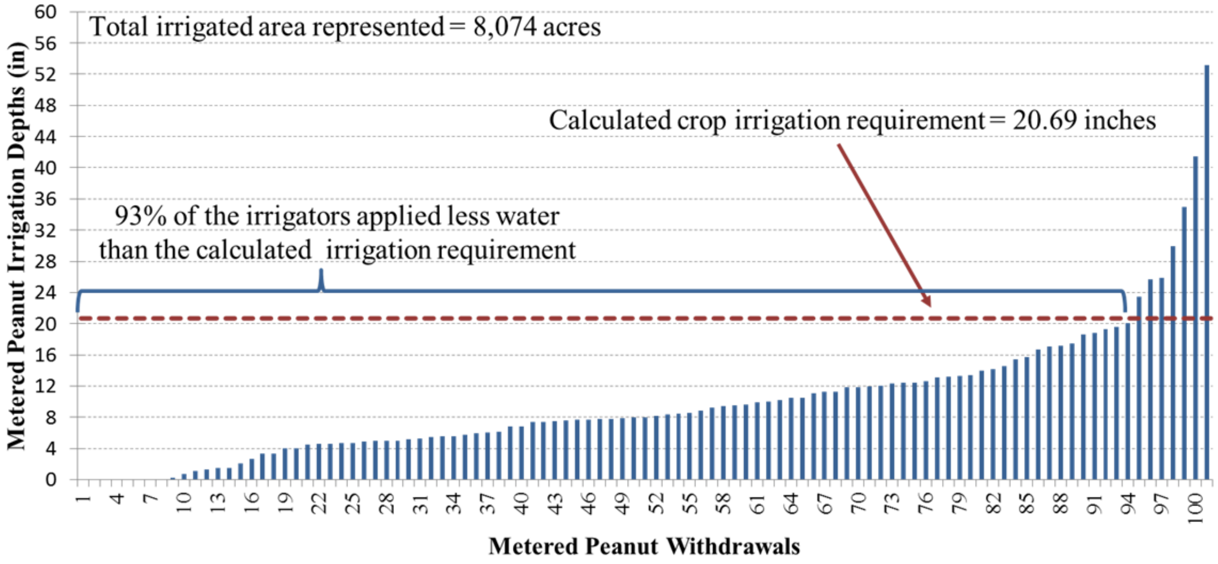
Source: GX-922, GX-923, GX-826, GX-927 (Georgia Flowmeter Data)

Irmak Demo. 11. Percentage of Metered Corn Farmers Irrigating Below Corn Irrigation Requirements in Miller County, 2012



Source: GX-922, GX-923, GX-826, GX-927 (Georgia Flowmeter Data)

Irmak Demo. 12. Percentage of Metered Peanut Farmers Irrigating Below Peanut Irrigation Requirements in Miller County, 2012



Source: GX-922, GX-923, GX-826, GX-927 (Georgia Flowmeter Data)

95. Overall, I found that 67.5% of Georgia farmers irrigated less than the crop irrigation requirement. In my opinion, the high percentage of farmers irrigating below the crop irrigation requirement shows that Georgia farmers are responsible and efficient water users. The

full county and crop results are provided in Irmak Demo. 13. Each of the counties below is entirely or largely within ACF Georgia.

Irmak Demo. 13. Percentage of Georgia Farmers Irrigating Below the Crop Irrigation Requirement in Georgia

County and Year	Cotton	Corn	Peanut
Decatur 2012	39.0%	72.2%	70.0%
Dooly 2011	48.0%	N/A	N/A
Miller 2012	80.0%	89.3%	93.1%
Mitchell 2011	57.0%	29.0%	68.0%
Sumter 2011	65.3%	100.0%	89.0%
Average	57.9%	74.9%	80.0%

Source: GX-922, GX-923, GX-826, GX-927 (Georgia Flowmeter Data)

96. As the founder and leader of the Nebraska Agricultural Water Management Network, which includes over 1,400 farmers, I am familiar with the irrigation practices of many farmers in Nebraska. The percentage of Georgia farmers irrigating less than the crop irrigation requirement is better than the percentage of farmers who do so in Nebraska, which has about 18% of the total irrigated land in the United States.

97. It is not unsurprising that there are some farmers with irrigation depths higher than the crop irrigation requirement. The Agricultural Metering Database cannot account for certain agricultural practices that can give the mistaken impression that some farmers are irrigating above crop irrigation requirements. The Agricultural Metering Database records only the crop being grown at the time the meter is read. Therefore, it does not account for the practice of multi-cropping, in which farmers plant two different crops in the same growing season. All else being equal, a farmer growing two crops will use more water than a farmer growing only one crop, and because the Agricultural Metering Database only records one crop, it overstates the irrigation depths applied by that farmer.

98. I also understand that, at least in some instances, the Agricultural Metering Database might not account for the fact that a farmer is using a single metered source to irrigate two or more fields. In that situation, the database may include acreage only for a single field, yet

will record water volume for the irrigation of two or more fields. That can give the misleading impression that the farmer is applying far more water than a crop requires.

99. It is also not unreasonable that there are some farmers growing corn with irrigation depths higher than the crop irrigation requirement. The Agricultural Metering Database does not necessarily account for different hybrids of corn, some of which have higher irrigation requirements than others. For example, sweet corn, which is often categorized under vegetable production, requires more water than field corn. Some farmers even grow two complete crops of sweet corn on the same field in a single season. The crop coefficients I used to calculate the irrigation requirements for corn were based on field corn, which I chose because it has an average water requirement among the different corn hybrids. All else being equal, a farmer growing sweet corn would use more water than a farmer growing field corn. Since the Agricultural Metering Database does not necessarily distinguish between these two distinct types of corn, it can give the mistaken impression that the farmer is irrigating above the irrigation requirement.

B. Findings Regarding Agricultural Productivity in Georgia

100. I also analyzed agricultural productivity, quantified in terms of yield per acre, of crops in ACF Georgia. I selected Mitchell County as an example, because it is located in the ACF Basin and is reasonably representative of the Basin as a whole.

101. I obtained yield per acre data for cotton, peanuts, and corn directly from the USDA National Agricultural Statistics Service. GX-1145 (NASS_Statistics_GA.xlsx)

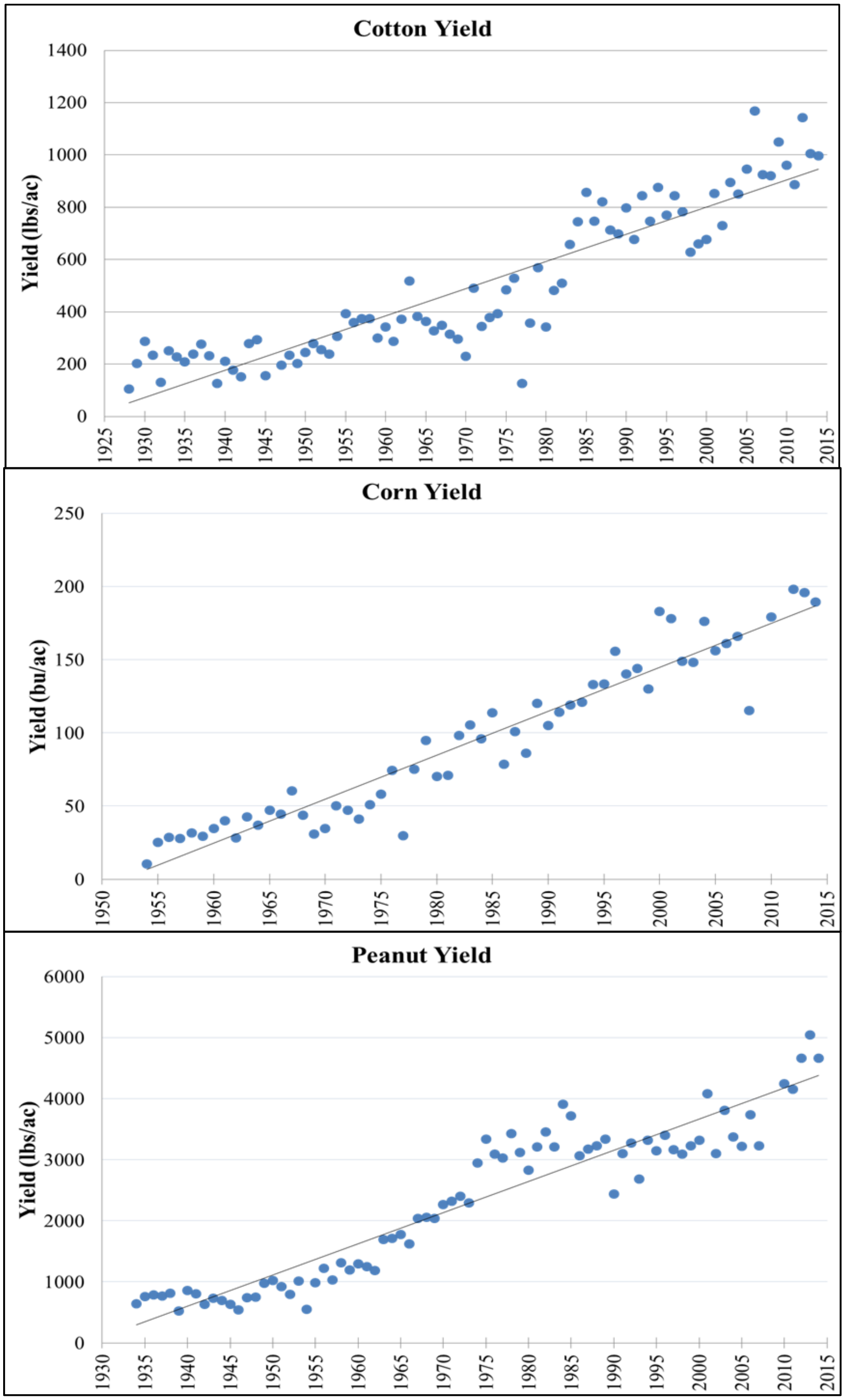
- GX-1145 is a true and correct copy of the data from the USDA on which I relied. Experts in my field regularly rely on data and statistics published by the USDA, and I reviewed this data in forming my expert opinions.

102. In reviewing this data, I found that agricultural productivity has consistently increased for cotton, peanuts, and corn in Mitchell County. Irmak Demo. 14 shows improvements in crop yields over time for cotton, corn, and peanuts in Mitchell County, Georgia.

103. To determine whether farmers are more efficient per unit of water they are using, I also calculated agricultural productivity per inch of crop water used in Mitchell County. I used

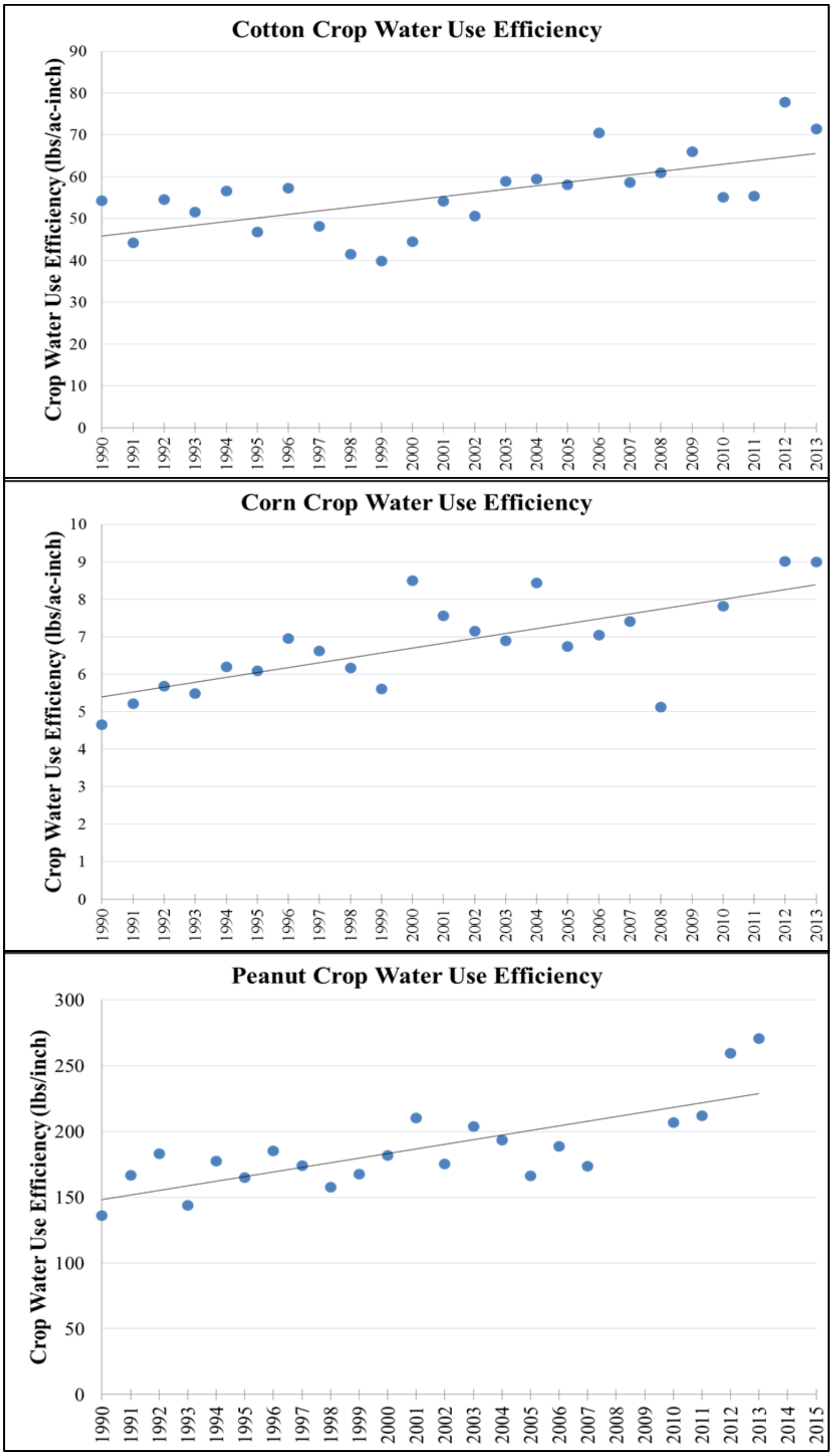
the yield per acre data from the USDA discussed above. For total crop water use, I took the yearly aggregate of daily crop ET that I estimated as described in Appendix 1, which represents total water use for that crop for the year. I then divided the yield per acre by the total crop ET for the year. I found that crop water use efficiency has increased in Georgia for corn, cotton, and peanuts. That means that farmers in Georgia now use less water to achieve a greater yield per acre than they did in 1990. These results are shown in Irmak Demo. 15.

Irmak Demo. 14. Improvements in Crop Yields Over Time for Cotton, Corn, and Peanuts in Mitchell County, Georgia



Source: GX-1145 (USDA National Agricultural Statistics Service Data)

Irmak Demo. 15. Improvements in Crop Water Use Efficiency Over Time for Cotton, Corn, and Peanuts in Mitchell County, GA.



Source: GX-1145 (USDA National Agricultural Statistics Service Data)

Appendix 1

A. Methodology for Calculating Crop Water Use

104. I performed an analysis to quantify crop water use in the ACF Basin in Georgia from 1990-2013 in Mitchell County and from 2003-2013 in Decatur, Dooly, Miller, and Sumter Counties.

105. How much water is required for a given crop is determined based on three key factors: crop ET (the combination of water transpired through plant leaves and water evaporated from plant leaves and soil surface), effective precipitation (the amount of water from precipitation that is actually stored in the crop effective root zone), and usable soil water, (the amount of water in the crop root zone that is available for uptake by the crop for growth, development, and yield production).

106. To determine crop irrigation requirements, I first performed long-term analysis of crop ET, effective precipitation, and soil water balance, to obtain daily and seasonal irrigation water requirements for the major irrigated commodity crops in ACF Georgia (cotton, peanuts, corn and soybean) for up to 24 individual growing seasons.

107. Then, to determine crop water use efficiency, I compared crop irrigation water requirements and crop yield data to actual water withdrawals in five representative counties in the ACF Georgia (representing a sample of more than 25% of the ACF Georgia counties). I used the measured irrigation application amounts that Georgia calculated from the flowmeters installed and maintained through its Agricultural Water Metering Program. The majority of flowmeter data (approximately 80-85%) is associated with a particular crop or crop rotation, which allows a comparison between the amount of irrigation water needed by the crop and the amount of irrigation water actually applied for those specific crops, subject to limitations regarding different crop hybrids and multi-cropping discussed in my testimony.

B. Calculating Crop-Specific Irrigation Requirements

108. Crop irrigation requirements can be calculated by determining crop evapotranspiration and subtracting the amount of water that the crop can take from precipitation and how much it can take from leftover soil water. The remainder represents the amount of

water that would need to come from irrigation. This value is then adjusted for the application efficiency of the irrigation system to get the irrigation requirement for that crop.[10]

C. Crop Evapotranspiration

109. Crop evapotranspiration ("crop ET") represents crop water use, which refers to how much water is being used by plants from precipitation, soil water, and irrigation applications. ET refers to the combined process of (i) evaporation from soil and plant surfaces and (ii) transpiration from plant canopies through the plant's stomata (openings in the plant's leaves) to the atmosphere, and is used to represent crop water use in agricultural sciences. ET represents the total amount of water used by the crop. As part of my analysis in this case, I calculated crop ET for corn, cotton, peanuts, and soybeans in multiple Georgia counties on a daily basis. Crop ET can be measured directly using advanced techniques. However, in practice, the most commonly used method of estimating the ET rate for a specific crop requires first calculating reference ET and then applying the proper crop coefficients to estimate actual crop ET. So I first calculated the ET of a reference crop, grass, on a daily basis using the widely accepted ASCE-Penman-Montieth equation.

110. The approach I used to estimate evapotranspiration is currently accepted by the scientific community as the most accurate method for determining crop water use. The International Commission for Irrigation and Drainage (ICID), The American Society of Civil Engineers-Environmental and Water Resources Institute (EWRI), and the Food and Agriculture Organization of the United Nations (FAO) Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements,[11] have all recommended that the FAO56-Penman-Monteith (FAO56-PM) equation method be used as the standard method to estimate ET and crop water requirements.[12]

---

[10] The formula for crop irrigation requirement is $IR = ET_C - (P_E + \Delta SW)$, where IR is irrigation requirement, ET_C is crop ET, P_E is effective precipitation, and ΔSW is the change in the soil water balance.

[11] Smith, M., Allen, R.G., Monteith, J.L., Perrier, A., Pereira, L., and Segeren, A, *Report of the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements*, UN-FAO, Rome, Italy, 54 p. (1991)

[12] Jensen, M.E., Burman, R.D., and Allen, R.G, *Evapotranspiration and Irrigation Water Requirements*, ASCE Manuals and Reports on Engineering Practices No70ASCE, New York, NY, 360 p. (1990)

111. After calculating the daily reference ET, I multiplied the daily reference ET by the crop-specific crop coefficient. Through earlier research into different crops, agricultural scientists have calculated daily crop coefficients for corn, cotton, peanuts, and soybeans based on the stage of the crop's lifecycle. Using a different standard growing season for each crop and the specific lifecycle-based crop coefficients for each crop available in the scientific literature, I determined the appropriate value of the crop coefficient for each crop for each particular day. I multiplied this value by the reference ET for that particular day to get a daily series of crop ET for each crop in each county. This gave me the total daily water use for each crop.

1. Effective Precipitation

112. After calculating the daily crop ET (i.e., daily crop water use), I then determined how much of that water use could be attributed to precipitation. Not all precipitation can be used by a crop. Some of the precipitation will run off and never infiltrate the soil. Some precipitation will infiltrate the soil but then percolate below the effective root zone of the crop, known as deep percolation. I assumed for my analysis that, given the sandy soils and low available water capacity of soils in ACF Georgia, that the long term effective precipitation rate in Georgia is 50%. I also calculated the effective precipitation rate using the effective precipitation formula from the 1993 USDA National Engineering Handbook. I calculated the long term effective precipitation rate for ACF Georgia to be 46.19%. In my opinion, this justifies a 50% effective precipitation rate assumption, which may actually overstate the amount of effective precipitation and thus understate the crop irrigation requirement.

2. Precipitation Data

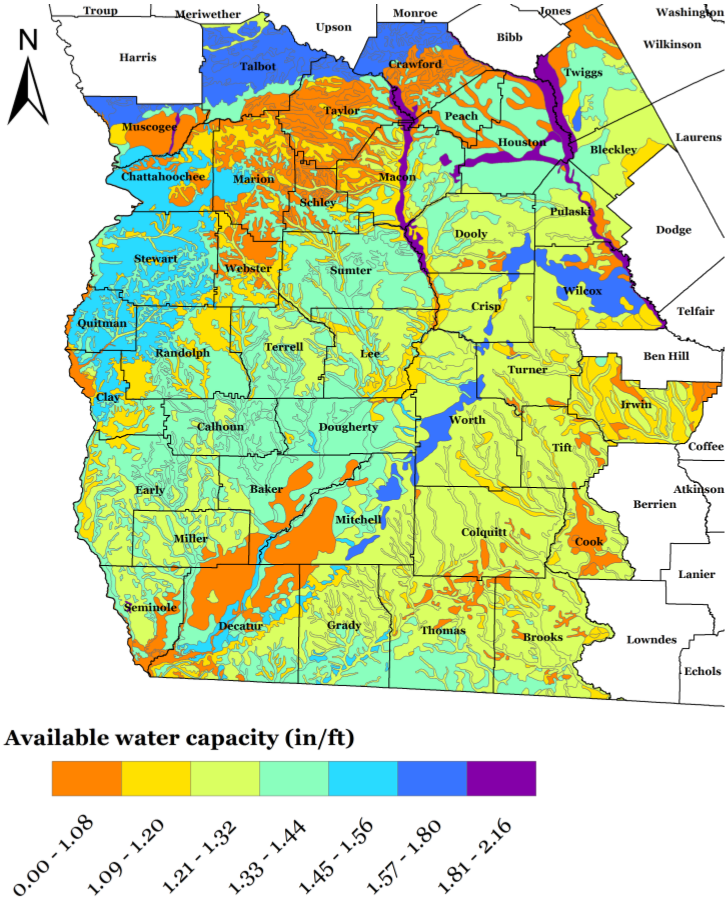
113. I used daily precipitation data available from the NOAA National Climate Data Center in my crop irrigation requirement calculations. The NOAA National Climate Data Center is a reliable source of precipitation data that is often relied upon for analyses of this nature. As is common with large climate datasets, the NOAA data has some "blank days" for each county, or days for which there is no recorded precipitation data. Florida suggested, inaccurately, during my deposition that because of these "blank days" my calculations had failed to account for a significant amount of precipitation and therefore, my crop irrigation requirements were too high.

114. Florida's suggestion is inaccurate. Blank days do not necessarily represent any missing precipitation, as they may represent days on which there was no precipitation. In addition, even if additional precipitation were included, this would not significantly change irrigation requirements in ACF Georgia due to the climate and soil factors discussed earlier. In any event, Florida's critique is no longer valid because I filled in the blank days using the precipitation data from the nearest available weather station. I used this filled precipitation data in my crop irrigation requirement calculations. The results show that my opinions regarding crop irrigation requirements and the percentage of farmers irrigating below those requirements are not substantially affected.

3. Soil Water Balance

115. I then estimated the amount of crop water use that could come from the soil. Precisely calculating soil water balance is a difficult task and such calculations often have significant uncertainty. However, I was able to make certain assumptions regarding the available water capacity and usable soil water of the soils in ACF Georgia. I reviewed soil data from the USDA-NRCS Web Soil Survey and created Irmak Demo. 16 below, a map showing the average available water capacity in ACF Georgia.

Irmak Demo. 16. Available Water Capacity in ACF Georgia



Source: USDA-NRCS Web Soil Survey

116. I calculated the average available water capacity in ACF Georgia to be about 1.3 inches per foot, which is consistent with Florida's calculations of the available water capacity in ACF Georgia. As Irmak Demo. 16 shows, in Subarea 4, where agricultural withdrawals have the greatest impact on streamflow, much of the soil has an available water capacity of less than 1.3 inches per foot. Nonetheless, I used the Basin-wide average of 1.3 inches per foot for available water capacity in my analyses. For my crop irrigation requirements analysis, I estimated the effective crop root zone for row crops to be about three feet, so the total available water capacity was 3.9 inches per 3 feet.

117. However, plants do not use all of the water available to them in the soils. The precise amount varies slightly between crops, but for corn, cotton, peanuts, and soybean, it is reasonable to assume that they can use 50 percent of available water capacity. GX-1235

(Physical Properties of Soil and Soil Water); GX-1246 (USDA Handbook). This value, known as the usable soil water, was 50% of 3.9 inches per 3 feet, or 1.95 inches per 3 feet.

118. I assumed that at the start of each growing season that the soil profile was fully saturated. In reality, soil is never fully saturated at the start of the growing season, so this assumption overstates the amount of usable soil water at the beginning of the season and can understate crop irrigation requirements.

119. I then assumed that each day, the soil would carryover all of the water in its profile up to the maximum usable soil water of 1.95 inches per 3 feet. If the crop has taken up all the water in the soil that day, then the soil carried over no water. If there was between zero inches and 1.95 inches of usable soil water left in the soil after the plant had withdrawn as much water as it needed from effective precipitation and the existing soil water, then I carried that full amount over to the next day. If there were more than 1.95 inches of usable soil water left, I carried over 1.95 inches of usable soil water to the next day. In reality, the soil would likely lose some of that water over the course of the day, so this overstates the amount of usable soil water at the beginning of the season and understates crop irrigation requirements.

4. Crop Irrigation Requirements

120. Based on the values calculated above, I calculated crop irrigation requirements on a daily basis. If that value was negative, then that meant the crop had satisfied its water needs from effective precipitation and soil water and no additional irrigation was needed. Thus, the crop irrigation requirement for that day was 0. Any leftover water was carried over in the soil, as discussed above. If the value was positive, then that meant the water from effective precipitation and the soil could not fully satisfy the crop's water needs and additional irrigation was necessary. This value is the net crop irrigation requirement for that day.

121. I then aggregated the net daily crop irrigation requirements across a season to determine the total net seasonal crop irrigation requirement. I assumed an irrigation application efficiency of 75% and divided the net seasonal irrigation requirement by that value to determine the gross seasonal crop irrigation requirement. This step is necessary because if a crop has a net seasonal requirement of 9 inches of water, and the farmer only applied 9 inches onto the field, some of that water would be lost to evaporation before it reached the crop. Based on the

efficiency of the system, a responsible farmer would have to apply slightly more water to ensure that the crop received all the water it needed. With a 75% efficiency baseline, to provide a crop with 9 inches of water, a farmer would need to apply 12 inches of water.

122. Farmers cannot be completely perfect in applying water. Even farmers using the most advanced technologies face uncertainties and technical limitations in irrigation. For example, a farmer irrigating based on soil moisture monitoring can only directly measure the moisture on one or two locations on his or her field and faces some uncertainty regarding the moisture in other areas of the field. In the face of that uncertainty, the farmer must make certain assumptions regarding the moisture in those other areas of the field in deciding when irrigation is necessary. Similarly, if it begins raining, the farmer faces uncertainty regarding how long the rain will last and must make a prediction on that matter before deciding to stop irrigation for that day, as a brief shower would not provide sufficient water for the crops. In addition, even though center pivots can provide water in small increments, they take multiple days to do a full revolution around a field, so a farmer may need to estimate the irrigation needs for multiple days at a time. For all of these reasons, it is my opinion that a farmer who irrigates slightly above the precise crop irrigation requirements is a responsible and efficient user of water.

123. Even in carefully controlled and managed research settings, determining the exact timing and amount of irrigation applications is extremely difficult. Therefore, agricultural researchers allow for about a 25% management adjustment from the gross irrigation requirement. For my analysis, I allowed a more conservative 15% management adjustment to the crop irrigation requirement, even though farmers often face even greater uncertainties in large scale agricultural production than researchers do with research fields. For these reasons, I believe that my 15% management adjustment is reasonable given the uncertainties and technical limitations faced by farmers in making irrigation management decisions.