No. 142, Original

In the

Supreme Court of the United States

STATE OF FLORIDA,
Plaintiff,
v.
STATE OF GEORGIA,
Defendant.

Before the Special Master
Hon. Ralph I. Lancaster

UPDATED PRE-FILED DIRECT TESTIMONY OF FLORIDA WITNESS DR. GEORGE M. HORNBERGER, PH.D, M.S.C.E., B.S.C.E.

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I. INTRODUCTION

1. I, Dr. George M. Hornberger, am a Distinguished University Professor and Director of the Institute for Energy and the Environment at Vanderbilt University. I am also an elected member of the National Academy of Engineers. I am an experienced hydrologist.

2. As I explain on page 1 of my textbook, *Elements of Physical Hydrology*, hydrology, literally "water science," is the study of the movement of water on and beneath the earth. Water on the surface of the earth, including water in a stream or river, is surface water. Water beneath the earth is called groundwater. Hydrology also involves the study of humans' impacts on both surface water and groundwater.

3. Hydrologists use a variety of tools, from basic data analysis to computer models, to evaluate how water resources like rivers are impacted by the activities of man, such as farming or use of water in cities or industry. In my testimony, I explain how I used basic hydrologic tools and generally accepted models and other methods to reach the following conclusions:

   a. **The Adverse Impacts of Georgia's Activities in the ACF Are Obvious and Pervasive**. What is occurring in the Apalachicola-Chattahoochee-Flint River Basin (the "ACF") is clear. Georgia's diversion, use, and consumption of water from the ACF are significant and readily apparent from a review of basic data. Activities in Georgia impact surface water flows and groundwater levels in the ACF. Groundwater is important because a large groundwater basin in the ACF (the Upper Floridan Aquifer) is a primary source of river flow that sustains the Apalachicola River, especially during drought. An aquifer is an underground geologic basin that can store and provide water to wells, springs, streams, and rivers.

b. Consumption of ACF water in Georgia is having a profound, adverse impact on the hydrology of the Apalachicola River. Measuring this impact requires an understanding of how hydrologists measure the flow of water. One common unit of measurement is cubic feet per second (cfs), the amount of water that passes a specific point on the river in one second. During droughts, Georgia consumption has caused river flow entering Florida to decline by about 4,000 cfs—a quantity roughly equivalent to two and a half times the flow of the Shenandoah River. This decline in flow corresponds is occurring at the time period when biologists for Florida opine the Apalachicola River is most in need of water.

c. Georgia consumption is causing harmful low flows to occur earlier in the year and at lower levels than ever seen in the historic record. The low flows are occurring far more frequently and are persisting for much longer periods of time than in the historic record. By every measure—magnitude, severity, frequency, and duration—the impacts are obvious and significant.

d. Farmers in Georgia are removing substantial amounts of water from the Upper Floridan Aquifer. When healthy, the Upper Floridan Aquifer sustains summer low flows in the lower Flint River, the lower Chattahoochee River, and the Apalachicola River. Agricultural pumping in Georgia has lowered the groundwater level of the Upper Floridan Aquifer by about four feet over several decades. This agricultural pumping is also having other dramatic impacts that are apparent during recent droughts: streams that never before had dried up now are running dry for long stretches during drought; normally clear springs adjacent to these streams are turning muddy due to lowered groundwater levels.

e. **Dramatic Increases in Georgia's Diversion, Use and Consumption of ACF Water**. Georgia consumption of ACF water has escalated significantly since about 1970, as reported by Dr. Sam Flewelling, and as I have independently confirmed from my own review of records. Irrigation in the Georgia portion of the ACF was not prevalent prior to 1970, but has dramatically increased since that time. These systems consume significant quantities of water. In addition, the population of Metropolitan Atlanta has grown by approximately 4 million since 1970, and water demands there also have risen materially. I have used both very conservative and more realistic methods to assess these demands, and their impacts to the ACF. My best estimates indicate that peak summertime water demands in the Georgia portion of the ACF now exceed 5,000 cfs.

f. **Climate, Which Has Been Stable, Is Not to Blame**. The climate of the ACF has remained relatively stable over past decades, as I have observed from the basic data and as Dr. Lettenmaier has reported from his statistical analyses of those same data. Rainfall is not disappearing and droughts are not getting worse. Dr. Lettenmaier and I used computer models, among other analyses, to demonstrate that Georgia consumption is the cause of major river flow declines in the ACF—not changes in climate and precipitation.

g. **Causation Is Clear**. In a region like the Georgia portion of the ACF, which has a stable climate and significant increases in consumptive use, basic principles of hydrology establish that human activities in Georgia are having a significant impact on reducing the amount of water in the Apalachicola River.

h. **Future Impacts Will Be Worse**. Given the absence of meaningful limits on irrigation in Georgia and projections of growth in municipal and industrial water use in the Atlanta area, the impacts I describe above are likely to become even more severe in the years ahead absent action now.

i. **Consumption Cap Will Address the Harms**. Placing a cap on Georgia's consumption as described in the scenarios presented by Florida's expert Dr. David Sunding will result in approximately 1,500 to over 2,000 cfs of additional water reaching the Apalachicola River during the critical low-flow drought months. This amount of water will mitigate the significant impacts I describe.

j. **Drought Can Be Anticipated; A Consumption Cap Is Workable**. The onset of drought can be reasonably anticipated using modern methods relying on basic data sources. This capability facilitates implementation of drought conservation measures like a consumption cap.

k. **There Is No Disappearing Water in Florida**. Georgia's claim that thousands of cfs of water are simply disappearing within the Apalachicola River is impossible. There is no use of water in the Apalachicola Basin that could possibly explain this, but it ***is*** explained by basic measurement error in the data upon which Georgia is relying. Water from a consumption cap in Georgia is not at risk of being squandered in Florida. Rather, it will be available to address hydrological and ecological harms resulting from Georgia's currently unrestrained consumption.

II. PROFESSIONAL BACKGROUND

4. I am currently a Professor of Civil and Environmental Engineering and Earth and Environmental Sciences at Vanderbilt University. I hold a Bachelor of Science in Civil Engineering (1965) and Master of Science in Civil Engineering (1967) from Drexel University, specializing in Hydrology. I also hold a Ph.D. in Hydrology from Stanford University (1970).

5. I am the first author of a well-regarded hydrology textbook *Elements of Physical Hydrology*. I have been a member of the National Academy of Engineers since I was elected by my peers in 1996. In 2001, I was named a National Associate of the National Academies of Sciences, Engineering, and Medicine.

6. My work in hydrology focuses on the ways in which climate, groundwater, surface water, and human activities involving water all interact. My current projects include work on adaptation to drought and on how cities' water conservation practices evolve. I also have extensive professional experience with groundwater hydrology and the assessment of human consumptive uses of water.

7. I have never before testified at trial as an expert, in hydrology or any other field. I was once deposed in a local land use matter, over 30 years ago, but have no other experience in litigation.

8. I have taught at Vanderbilt University since 2008. Before my time at Vanderbilt, most of my professional career was spent at the University of Virginia, where I taught from 1970 to 2008.

9. I have also spent time as a Visiting Scientist at the U.S. Geological Survey (USGS) (1990-1991), as well as several other institutions.

10. In addition to my textbook, *Elements of Physical Hydrology*, I am the author or co-author of numerous books and book chapters on hydrology as well as over 160 articles on hydrology in refereed journals.

11. I have expertise in groundwater hydrology, as well as surface water hydrology, and in consumptive uses. In this case, I led a team with Dr. David Langseth and Dr. Samuel Flewelling, each of whom prepared an expert report and testified at deposition. Dr. Langseth's area of focus in this case was groundwater, while Dr. Flewelling's was consumptive use. Collaborating with other scholars is commonplace in hydrology and I am very familiar with their work. I agree with their work based on my own independent evaluation of their methods, analysis, and conclusions. I rely upon their work in this testimony.

III. KEY TERMS AND CONCEPTS

12. My testimony relies upon certain key hydrological terms and fundamental concepts which I describe below.

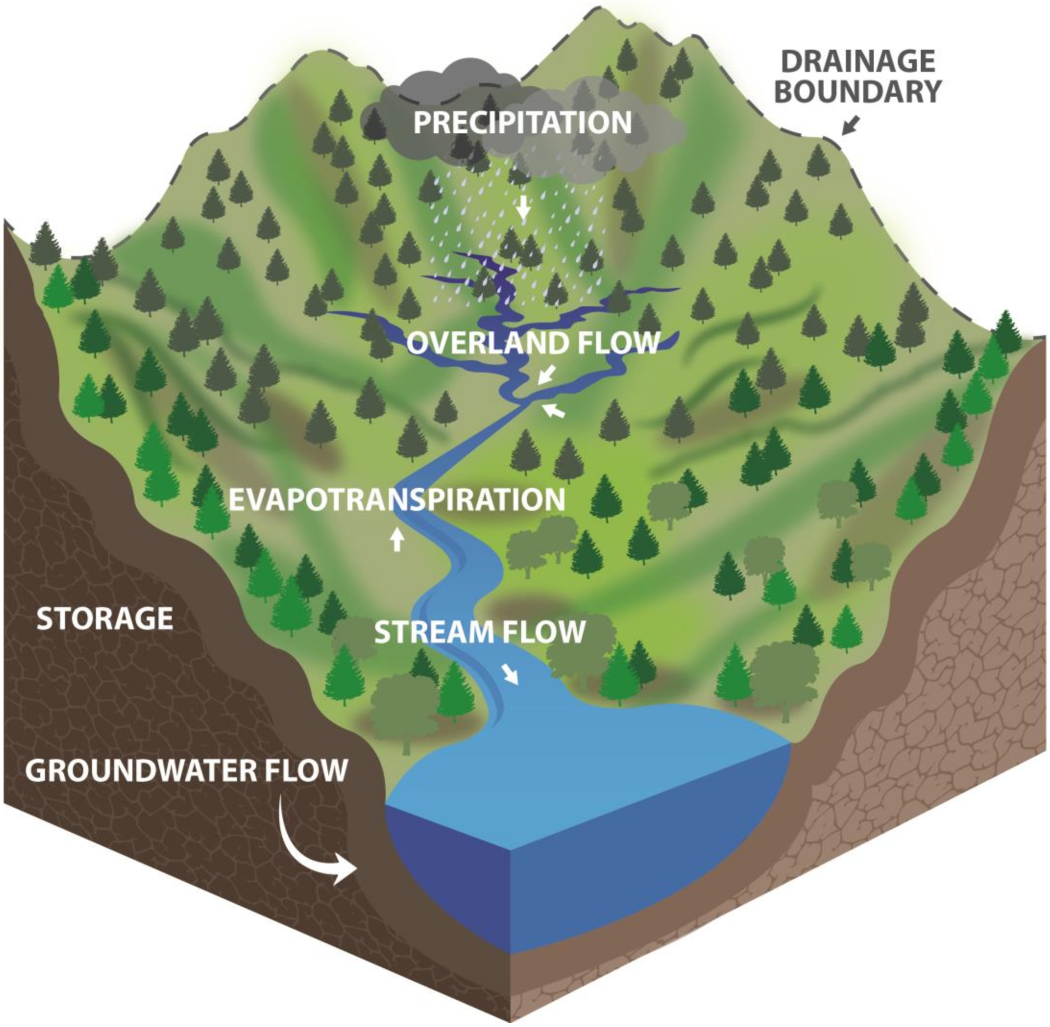

Figure 1. Diagram of a River Basin

13. River Basin. A river basin such as the ACF is the land mass that drains to a particular river (or, in this case, three interconnected rivers) and its tributary streams. As illustrated in Figure 1, a basin is defined by a drainage boundary, which marks the edge of the area that drains into and feeds the river system. A river basin sometimes is referred to as a watershed. The ACF is made up of three interconnected river basins, one for each of the named rivers.

14. Streamflow. Streamflow is a term I generally use to describe water flowing in rivers and streams. Streamflow is also sometimes called runoff.

15. Groundwater Basin. A groundwater basin, or aquifer, such as the Upper Floridan Aquifer, is a discrete source of groundwater that people can access through groundwater pumping. Figure 1 also shows how groundwater can flow to and feed a river. The boundaries of a groundwater basin can be very different from the boundaries of a river basin. In this case, the Upper Floridan Aquifer is the aquifer beneath significant portions of the southern portion of the ACF in Georgia.

16. Groundwater. Groundwater refers to water stored in a groundwater basin or aquifer which typically flows toward rivers and streams. Groundwater can directly feed streamflow on the surface or, at times, streamflow can flow into the groundwater.

17. Groundwater table. The top elevation of the water in a groundwater basin or aquifer forms a surface called the groundwater table.

18. Precipitation and gridded rainfall data. In the ACF, the dominant form of precipitation is rainfall, which is typically measured at specific locations with a rain gage—a small container open to the sky that collects rainfall. Area-wide rainfall data are typically estimated by taking measurements from numerous rain gages and using them to create a set of rainfall estimates at a series of evenly-spaced points, which is often called gridded rainfall data. (Similar grids are prepared for temperature data.) The National Oceanic and Atmospheric Administration (NOAA) and other prestigious public and private entities maintain gridded rainfall data for most of the U.S., including the ACF Basin.

19. Evapotranspiration. Evapotranspiration is the combination of *evaporation* of water directly from soil and open water bodies, and *transpiration*—the evaporation of water from plant leaves. Evapotranspiration is a natural process by which rainfall is lost from a watershed as water vapor is carried away by the atmosphere before it can become streamflow or

groundwater. *The amount of water flowing in rivers or streams and through aquifers is equal to total rainfall minus evapotranspiration. Human appropriation of water increases evapotranspiration and thus reduces the flow of streams and groundwater.*

20. Calculating Evapotranspiration. In theory, evapotranspiration can be measured with sensors, but only with sophisticated, research-level equipment over relatively small areas. Hydrologists regularly calculate evapotranspiration from climate variables and models. Standard climate variables (*i.e.*, temperature, relative humidity, wind speed, solar radiation) from reliable sources were used in this case to calculate evapotranspiration.

21. Water withdrawals. Water withdrawals are the amount of water removed from a stream or pumped from groundwater for a particular human use. Water withdrawn from a source can be returned to a river (referred to as a *return flow*) or it can be consumed, *i.e.*, evaporated or transpired (referred to as *consumptive use*).

22. Consumptive use. Consumptive use is a term I use to describe human activity that leads to the use of water such that the water does not return to a river or stream. Evaporation from irrigated plants is one example. Evaporation from farm ponds is another, as is evaporation in connection with lawn watering.

23. Basin exports. Water piped out of a river basin to somewhere else is known as a basin export. Georgia exports water from the ACF, the net effect of which is a loss of ACF river flow.

24. Streamflow depletion. Streamflow depletion means removing water from a river, stream, or lake due to consumptive use. This term is different from the term consumptive use as it specifically refers to how much water has been removed from a river, stream, or lake at a given time.

25. Stream gage. Stream gages operated by the federal agency USGS measure the height (also known as stage) of the river. This measurement is combined with information about the velocity of the river flow and a formula called a "rating curve" to convert continuous measurements of river depth into a streamflow measurement. Many (but not all) of the USGS stream gages in the ACF have long-term and relatively complete records providing empirical evidence of flow conditions and a reliable foundation for my analysis. Gages I used for my analysis are shown on Figure 2 below and include:

- The Chattahoochee Gage (USGS Gage No. 02358000), on the Apalachicola River near Chattahoochee, Florida—just below Lake Seminole and the Georgia-Florida state line.
- The Bainbridge Gage (USGS Gage No. 02356000), the southernmost gage on the Flint River above Lake Seminole.
- The Albany Gage (USGS Gage No. 02352500), on the Flint River approximately 55 miles upstream of the Bainbridge Gage.
- The Newton Gage (USGS Gage No. 02353000), on the Flint River approximately 30 miles upstream of the Bainbridge Gage.
- The Iron City Gage (USGS Gage No. 02357000), on Spring Creek, a river located in the Flint Basin and draining to Lake Seminole.
- The Columbia Gage (USGS Gage No. 02343801), the southernmost gage on the Chattahoochee River above Lake Seminole.
- The Whitesburg Gage (USGS Gage No. 02338000), located on the Chattahoochee River approximately 40 miles south of Atlanta and 180 river miles upstream of the Columbia Gage.
- The Sumatra Gage (USGS Gage No. 02359170), the southernmost gage on the Apalachicola River, approximately 80 river miles south of the Chattahoochee Gage and about 20 river miles above Apalachicola Bay.

26. Cubic feet per second (cfs). As noted earlier, the term cfs is a unit of measurement to describe the amount of water flow. The unit millions of gallons per day (mgd) is also commonly used to describe quantities of water. One cfs is roughly equivalent to 0.65 mgd.

27. Rainfall/runoff models. Rainfall/runoff models are state-of-the-art computer modeling tools that use the basic data for rainfall, temperature, relative humidity, wind speed, solar radiation, and land cover to estimate river flow. To ensure that the models provide reliable estimates, the results are compared to actual streamflow records from USGS gaging stations in a process called "calibration." In connection with my work, I used the Precipitation Runoff Modeling System (PRMS) model that was developed by the USGS for the ACF Basin. I calibrated PRMS to the USGS gage record for the pre-1955 period so that I could estimate what the river flows would be in recent decades under conditions relatively unimpacted by humans. PRMS is a reliable tool to estimate how streamflow depletions in Georgia have impacted the Apalachicola River.

28. ResSim. ResSim is a planning model maintained by the Army Corps in connection with its management of federal dams and reservoirs, including those in the ACF. ResSim is not used to actually administer operation of the dams and does not accurately predict actual flows in certain key drought periods.

IV. BACKGROUND ON ACF BASIN HYDROLOGY

29. The hydrology of the Apalachicola River is dependent upon the upstream Flint and Chattahoochee Rivers. Fundamentally, what happens upstream drives what happens downstream. These three rivers comprise the ACF, which spans an area of approximately 19,500 square miles across eastern Alabama (15% of the total basin), western Georgia (74%) and the Florida Panhandle (11%). (See Figure 2.) The Flint and Chattahoochee Rivers flow from northern Georgia and meet at Lake Seminole to form the Apalachicola River, which flows south through the Florida Panhandle into the Apalachicola Bay.

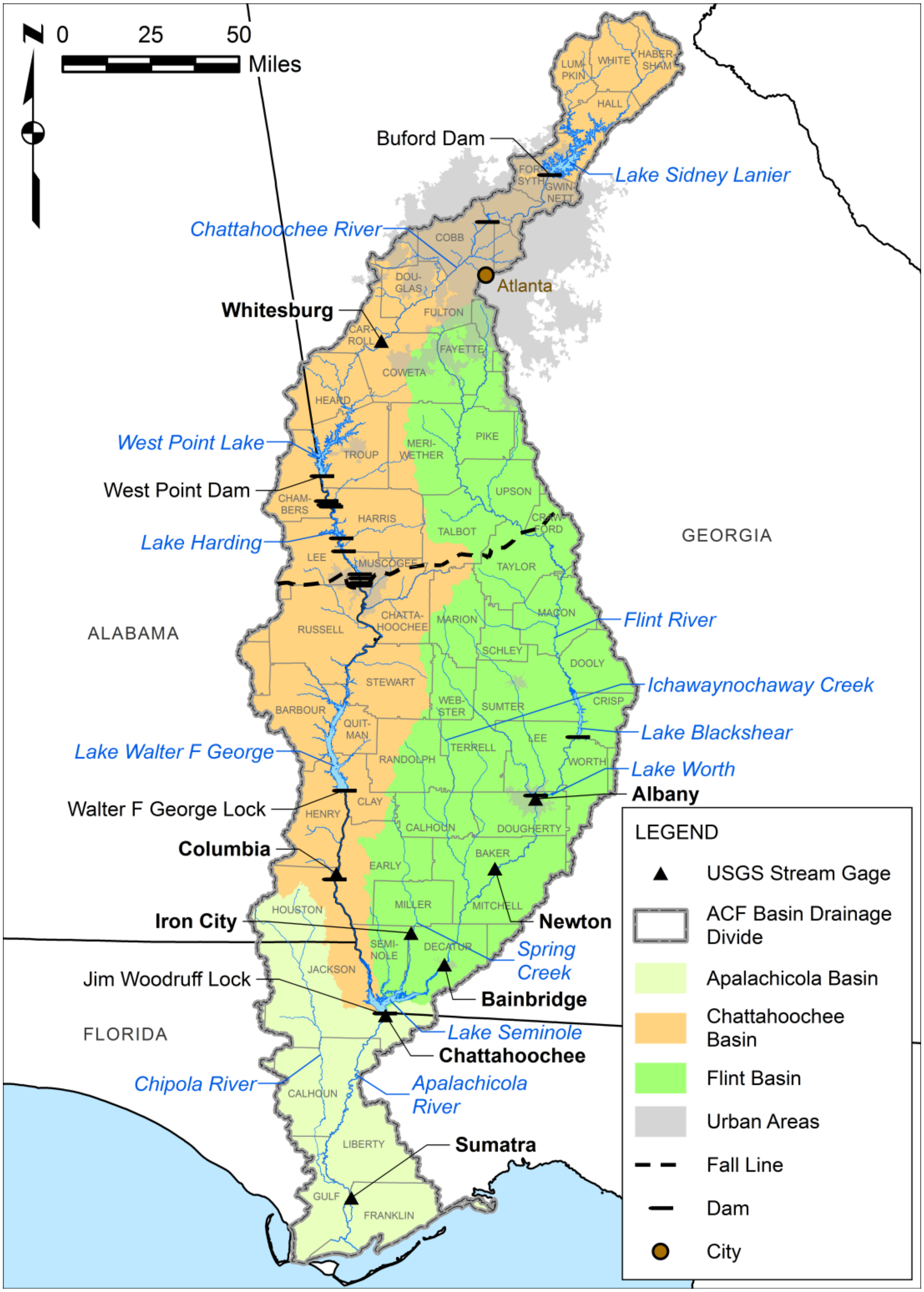

Figure 2. Map of the ACF Basin

30. Water in the ACF flows generally from north to south. The Chattahoochee River, approximately 440 miles long in all, arises north of Atlanta, in the foothills of the Blue Ridge Mountains, collects in Lake Lanier behind the Buford Dam, then meanders approximately 342 miles before it reaches Lake Seminole. The City of Atlanta is located approximately 50 miles south of Lake Lanier. Between Lake Lanier and Lake Seminole, there are two other federal impoundments (lakes impounded behind dams)—West Point Reservoir and Lake Walter F. George—where a significant amount of water is stored.

31. Immediately to the east of, and adjacent to, the Chattahoochee River Basin lies the Flint River Basin, which begins just south of Hartsfield International Airport serving the Metropolitan Atlanta area. The Flint River flows approximately 345 miles south before it reaches Lake Seminole and mixes with the water from the Chattahoochee River. There are no federal impoundments on the Flint River. There are a few non-federal reservoirs, none of which have significant storage. Thus, Flint River water flows relatively unimpeded to the Georgia/Florida border, and then on to Florida.

32. Average rainfall in the portion of the ACF Basin above the Chattahoochee Gage (which lies just below Lake Seminole) is 51.5 inches per year, a rather good amount of rainfall, underscoring why it is in the low rainfall years that the major problems arise. Average air temperatures are about 64.2º F, with a summer average of about 78.2º F. I present these summary rainfall and temperature values based on averages from the Livneh et al gridded climate dataset, *see* FX-750. This 2013 University of Washington dataset (and subsequent 2015 extension) provides modeled hydroclimatological data based on observed variables, like precipitation and temperature, and derived variables based on these observations, to generate hydroclimate data across the entire contiguous United States. This is a highly respected dataset

based on generally accepted scientific principles and methods, which is commonly used by experts in my field to assess hydroclimate data.

33. Flow out of Lake Seminole forms the Apalachicola River, which runs 106 miles south before entering Apalachicola Bay. There are no dams on the Apalachicola River. Apalachicola Bay is a mixture of fresh and salt water called an estuary, and is protected from the open Gulf of Mexico by a series of barrier islands.

34. The Upper Floridan Aquifer is a naturally-occurring, massive underground basin. The Upper Floridan is an important source of water to the Lower Flint and Lower Chattahoochee Rivers, as these rivers and their tributaries cut directly into the aquifer in many places, allowing groundwater in the Upper Floridan under natural conditions to discharge directly into these rivers. Pumping in Georgia reverses this natural process, causing river water to flow into the Upper Floridan to feed the pumping demand. Under natural conditions, the Upper Floridan provides an everyday source of water to these surface water bodies, whether or not it is raining. The term for river flow originating from groundwater is “base flow.”

35. Pumping from the Upper Floridan Aquifer provides tremendous quantities of water for agricultural use in the Georgia portion of the ACF. This irrigation pressure on the Upper Floridan Aquifer in Georgia is known to have lowered the groundwater table, and threatens the ability of the Upper Floridan to provide base flow, which is a critical component of the flows that reach Florida during dry and drought periods.

V. THE HYDROLOGY OF THE CHATTAHOOCHEE AND FLINT RIVER BASINS HAS FUNDAMENTALLY CHANGED IN RECENT DECADES, ADVERSELY IMPACTING THE APALACHICOLA RIVER

36. Hydrologic conditions in the Chattahoochee and Flint River Basins have fundamentally changed in recent decades, resulting in dramatic declines in flow to the Apalachicola River in Florida during low-flow summer months. Numerous hydrologic

phenomena demonstrate these changes, including significant declines in surface water flow, groundwater levels, and the relationship between rainfall and runoff (also called streamflow).

37. I find that Georgia's consumption is greatly exacerbating the impacts of drought. The modern droughts (post-1970) themselves have not been any more severe than historic droughts, and in some instances have been more moderate. It is Georgia's consumption that is making matters so much worse than in historic droughts.

38. Georgia officials and experts who have looked at this issue agree that the impacts of consumption during drought are material. For example, in connection with my research and analysis in this matter, I reviewed certain public records to evaluate issues related to water consumption. Hydrologists often review such public records to understand how federal and state government bodies evaluate the impact various activities have on flow. Exhibit FX-622 is one such record. It is a joint statement issued by USGS and the Georgia Soil and Water Conservation Commission ("GSWCC") in December 2011. According to its Internet website, GSWCC is a Georgia public body formed to protect, conserve, and improve the soil and water resources of the State of Georgia. Exhibit FX-622 states that "[s]ince the advent of center-pivot irrigation in the mid-1970s, extensive irrigation-dependent agricultural development in the lower Flint River Basin has exacerbated drought year low flows, which now occur earlier in the year and with unprecedented severity, compared with streamflow conditions that had occurred before irrigation became widespread." (USGS 2011, FX-622 at 1.)

39. As part of my review of public records, I analyzed the Flint River Basin Regional Water Development and Conservation Plan (the "Flint River Plan"), adopted by the Georgia Department of Natural Resources Environmental Protection Division (EPD) in 2006. The Flint River Plan "was initiated in October 1999 in response to a prolonged drought, increased

agricultural irrigation in southwest Georgia since the late 1970's, and scientific studies that predicted severe impacts on streamflow in the Flint River Basin (FRB) due to withdrawals from area streams and the Floridan aquifer." Among other things, the Flint River Plan finds that "[s]ince extensive development of irrigation in the lower Flint River Basin, drought year low flows are reached sooner and are lower than before irrigation became widespread," and that "[a]gricultural withdrawals from the Floridan aquifer decrease base flow to streams that are in hydrologic connection with the Floridan aquifer." (Georgia EPD 2006, JX-21 at 22.)

40. Scientists regularly review the work of others, and I reviewed a large number of documents (*e.g.*, scientific reports) addressing hydrological topics relevant to the ACF Basin. For example,, I reviewed a 2009 report titled, "Impacts of Agricultural Pumping on Select Streams in Southwestern Georgia" by David W. Hicks and Stephen W. Golloday, two Georgia scientists from the J. W. Jones Ecological Research Center. Hicks and Golladay performed a long-term review of climate and hydrology in Southwest Georgia, spanning more than 60 years. They concluded that neither changes in precipitation patterns nor recent droughts could explain declines in surface flows. They also found that "water use is the primary factor causing record low streamflow and other alterations to regional hydrology." (*See* Golladay & Hicks 2009, FX-49d1 at 27.)

41. These materials are wholly consistent with what I determined based on my review of the data. In addition, I know from decades of experience and basic principles of hydrology that, under stable climate conditions, low flows will not decline without substantial human influence.

A. Impacts to the Apalachicola River From Georgia's Consumptive Use Are Obvious From The Data

42. Lower flows and more frequent low flows on the Apalachicola River are evident from what I refer to as basic data—things like river flow, air temperature, and rainfall. There are extensive data for the ACF, going back nearly a century. Looking at these data alone, it is clear to me that there has been a substantial and fundamental change to the hydrology of the ACF. In particular, state-line flows to the Apalachicola River in low-flow summer months have declined by several thousand cfs in recent decades. The climate has varied over time (as it always does any place on the planet) but overall has been stable, so the only other possible cause for declining flow is consumptive use of water in Georgia.

43. On its National Water Information System website, the USGS maintains records of river and stream flow at gages across the United States, including in the ACF Basin. As a hydrologist I regularly analyze the gage data from these USGS records. The gage data I refer to in my testimony is publicly available on USGS's website (see http://waterdata.usgs.gov/ga/nwis/rt for gages in Georgia and http://waterdata.usgs.gov/fl/nwis/rt for gages in Florida). Additional information on USGS stream gages is available at http://pubs.usgs.gov/fs/2005/3131/FS2005-3131.pdf. As an experienced hydrologist, I regularly review publicly available streamflow data to confirm its reliability.

44. The USGS monitors streamflow data at numerous locations throughout the ACF Basin. The Chattahoochee Gage, which is located in the Apalachicola River, immediately downstream of the Jim Woodruff Dam, provides reliable data for measuring the flow that enters the Apalachicola River near the Florida-Georgia border. USGS flow records for the Chattahoochee Gage show that the magnitude, frequency, and duration of low flows entering

Florida from Georgia are much more severe in recent decades than before 1970. After 1970, Georgia's consumptive use began to escalate significantly, as discussed below.

45. I employed generally accepted calculation methods to evaluate streamflow data from numerous gages, including the Chattahoochee Gage. For example, I calculated average monthly flows at the Chattahoochee Gage for various time periods. These averages establish that streamflow entering Florida from the Woodruff Dam has declined dramatically during the past 20 years. (JX-128 (USGS monthly gage data for Chattahoochee Gage).)

46. Dr. David Allen is an accomplished biologist working as an expert on this case for the State of Florida. Based on his work here, Dr. Allen has identified what he describes as a biologically important threshold at the Chattahoochee Gage: 6,000 cfs. Average monthly flows this low were quite rare before 1980, occurring in only seven months in over fifty years. Since then, low-flow months have become increasingly common. There were 14 months averaging flows below 6,000 cfs in 2011 and 2012 alone.

47. The Bainbridge Gage is the last USGS gage on the Flint River, located just upstream of Lake Seminole. The same phenomenon of dramatically declining flows can be observed on the Flint River at the Bainbridge Gage in Georgia, where the USGS stream gage record dates back to 1907 (with a gap in operation between 1971 and 2001). (See FX-259 (USGS monthly gage data for Bainbridge Gage).) Examining the record of monthly average USGS Bainbridge Gage data, I determined that, historically, flows at this gage seldom dropped below 2,500 cfs (in only 5 months for the entire 1907 to 1970 record), so I used that threshold as a comparison. As can be seen from Exhibit FX-259, in the 21st century, Bainbridge flow patterns during dry periods show dramatic change from the pre-1970 historic period. Since 2001

monthly average flow has fallen below 2,500 cfs much earlier in the year than had ever occurred before:

- 2002: below 2,500 cfs for 4 months straight starting in June;
- 2006: below 2,500 cfs for 4 of 5 months starting in June;
- 2007: below 2,500 cfs for 6 months straight starting in June;
- 2008: below 2,500 cfs for June and July;
- 2011: below 2,500 cfs for 6 months straight starting in June; and
- 2012: below 2,500 cfs for 8 months straight from May through December.

48. In addition, streamflow values far below the historic low value of 2,217 cfs of October 1954 have occurred since 2001. There were 15 months where the monthly value was below 2,000 cfs, and even two months where the monthly value fell below 1,500 cfs.

49. In addition to evaluating streamflow data, I also evaluated publicly available temperature and precipitation data from numerous stations to determine whether, and to what extent, temperature and precipitation may have contributed to these low flows. My analysis of precipitation data in the area of the ACF Basin watershed that flows down to the Chattahoochee Gage, using the Livneh dataset described above, shows that flows have declined despite the fact that the climate has remained generally stable.

50. As an example, Table 1 shows a comparison of two key climate variables, precipitation and temperature, and state-line Apalachicola River flows in two sets of back-to-back drought years. One set of years (1954-1955) is before the growth in Georgia's consumptive use and the other is a recent pair of years with modern consumptive use levels (2011-2012).

Table 1. Comparison of the 1954-1955 Drought to the 2011-2012 Drought for the Apalachicola River Just Below the Georgia/Florida State Line (Chattahoochee Gage)

	First Year of Drought		Second Year of Drought	
	1954	2011	1955	2012
June-Sept. Precipitation (inches)	10.4	14.5	15.8	16.7
June-Sept. Air Temperature (ºF)	81.0	79.5	78.2	77.3
June-Sept. Streamflow (cfs)	8,968	5,566	9,563	5,419
Annual Precipitation. (inches)[1]	30.8	42.2	40.5	42.3
Annual Air Temperature (ºF)	65.6	64.1	65.0	65.0
Annual Streamflow (cfs)	14,381	9,796	11,223	7,599

51. There was more rainfall in the 2011-2012 drought than in the 1954-1955 drought, and temperature was approximately the same in both periods. Yet flow on the Apalachicola River from Georgia was approximately 3,500 to 4,000 cfs lower in the modern drought. This decline in flow was clearly not caused by climate (rainfall was higher in the modern drought), and the only remaining interpretation is that these declines are caused by human water consumption.

52. Comparing basic hydrologic conditions in the first and second years of each drought (1954 vs. 2011 and 1955 vs. 2012) provides further insights. Much less rain in 1954 produced much more flow, as compared with 2011, whether looking at the whole year or June to September (approximately 4,600 cfs and 3,400 cfs, respectively). Similarly, for about the same rainfall in 1955 and 2012, flows in 1955 were much higher both for the whole year and from June to September (3,600 cfs and 4,100 cfs, respectively). In 2012, average June-to-September flows were *lower* than June-to-September flows in 2011 despite increased precipitation. In contrast, in 1955, June-to-September flows were greater than June-to-September flows in 1954. This information indicates that summer-month flows in multi-year droughts are worse in recent years than they were in the past, with adverse effects compounding during the second year of a

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[1] Precipitation and temperature are presented from the dataset used in my expert report (Livneh et al).

two-year drought because of cumulative declines in water stored as groundwater (as discussed below).

53. Another severe drought occurred in 1931. A comparison of streamflows, temperatures and precipitation from 1931 to those in 2011 and 2012 reveals a similar dramatic decrease in streamflows in the recent drought, even though the 1931 drought was significantly more severe and temperatures were slightly higher. As shown in Table 2, the Chattahoochee Gage shows a decline of approximately 3,600 cfs from the summer flows in 1931 to those of 2011. Streamflow data here were obtained using USGS measurements at the Chattahoochee Gage (*see* JX-128), while the temperature and precipitation data were derived using the Livneh dataset.

Table 2. Comparison of the 1931 Drought to the 2011-2012 Drought for the Apalachicola River Just Below the Georgia/Florida State Line

	1931	2011	2012
June-Sept. Precip. (inches)	12.7	14.5	16.7
June-Sept. Air Temp (ºF)	80.5	79.5	77.3
June-Sept. Streamflow (cfs)	9,202	5,566	5,419
Annual precip. (inches)[2]	37.4	42.2	42.3
Annual Air Temp (ºF)	65.5	64.1	65.0
Annual Streamflow (cfs)	13,996	9,796	7,599

54. Another way to look at how low flows have changed is to select a low river flow threshold, such as 6,000 cfs, and count the number of individual days below that value each year. Using USGS data (JX-128), I analyzed streamflow data from the Chattahoochee Gage and determined that in the last few decades, the frequency of low-flow days has increased sharply. (Table 3.) Before 1970, flows below 6,000 cfs at the Chattahoochee Gage were rare—occurring

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[2] Precipitation and temperature are presented from the dataset used in my expert report (Livneh et al). For further information, see description of gridded climate data sets in Dr. Lettenmaier's testimony.

on average about 5 days a year. Since 2003, the Apalachicola River has experienced these low levels an average of 71 days a year. Similarly, the number of *consecutive* days with flows below 6,000 cfs has increased. (Figure 3.) Before 1970, consecutive days of flow below 6,000 cfs were rare. But since then, repeated long stretches of these very low flows have occurred, including one in 2012 that stretched 131 days (and another for 87 days).

Table 3. **Average Number of Days Per Year with Flow Below Certain Thresholds on the Apalachicola River Just South of the Florida-Georgia State Line (Chattahoochee Gage)** (Table 4 in my Feb. 29, 2016 Expert Report, FX-785)

Threshold Discharge	**1921-1970**	**1970-2013**	**1992-2013**	**2003-2013**
6,000 cfs	5.2 days	29.8 days	50.6 days	71 days
5,500 cfs	2.6 days	19 days	32.7 days	54 days
5,400 cfs	1.9 days	16.3 days	28.0 days	47.2 days
5,300 cfs	1.5 days	13.1 days	22.2 days	37.8 days
5,200 cfs	1.0 day	11.4 days	19.3 days	33.7 days
5,100 cfs	0.2 days	6.0 days	9.2 days	14.8 days
5,000 cfs	0 days	3.0 days	3.8 days	4.5 days

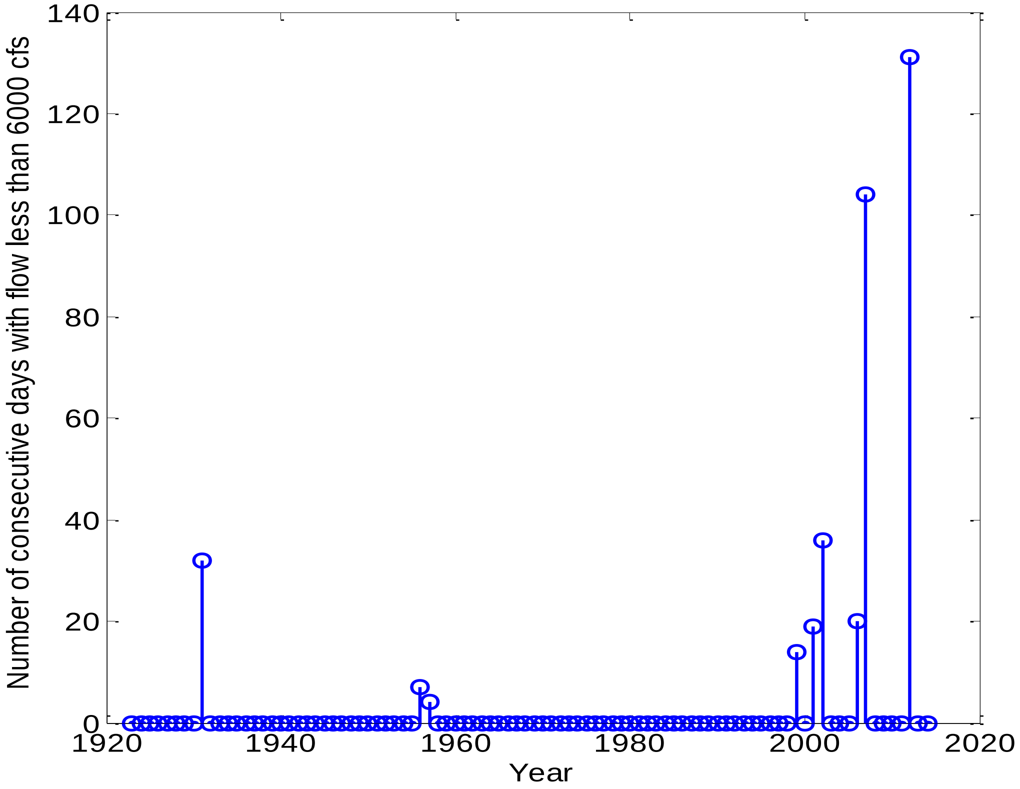


Figure 3. Number of Consecutive Days Below 6,000 cfs at Chattahoochee Gage (Figure 8 in my Feb. 29, 2016 Expert Report)

55. These significant hydrologic changes in the ACF occur in even more dramatic ways in some tributary streams. One of the most heavily irrigated areas in the Georgia ACF Basin is the Spring Creek region, which is in the lower Flint River Basin. The 2006 Flint River Basin Plan reports that the Spring Creek sub-basin has a very high "density of irrigation," and a "very close connection between the Floridan aquifer and surface water." (Georgia EPD 2006, JX-21 at 22-23.)

56. Spring Creek flows through the heart of the region in southwest Georgia that is the epicenter of the state's tremendous growth in irrigation. Before recent decades, there was always measurable flow in Spring Creek, even during past severe droughts. In recent decades, however, the creek has run completely dry for long periods. From 1980 to 2014, the USGS gage

at Iron City records 366 days with no flow (zero cfs). The lowest flows at Spring Creek also have become much lower and much more frequent. Before 1980, at the USGS Spring Creek gage at Iron City, there were no days with measured discharge at or below 9 cfs. (In 1954, a low flow of 9.1 cfs was recorded.) Days with low flows at or below the 9 cfs threshold after 1980 were numerous—1041 days in total.

57. Finally, another standard approach in my discipline is to compare relevant regulatory criteria with streamflow data. In that regard, I am aware that the U.S. Fish & Wildlife Service (FWS) and the U.S. Environmental Protection Agency (U.S. EPA) developed "Instream Flow Guidelines for the ACT and ACF Basins Interstate Water Allocation Formula" (FX-599, 1999 Guidelines) to be used by Florida and Georgia in determining an appropriate allocation of water within the ACF Basin. The federal agencies described the purposes of the Guidelines this way: The Guidelines "represent a determination of flow regime features that are necessary for monitoring the present structure and function of the river ecosystem." These criteria address the health of the ecosystem as a whole, not simply whether a particular species may face complete extinction in every location in the system. I obtained a genuine copy of, and reviewed the 1999 Guidelines, and find them to be the type of regulatory information that commonly is used in my discipline. I therefore proceeded to compare the 1999 Guidelines to relevant streamflow data.

58. My comparison shows that low summer flows at the Chattahoochee gage on the Apalachicola River have been in chronic non-compliance with the 1999 U.S. EPA/FWS Guidelines since 2000. Similar results are apparent for the Bainbridge gage near the southern end of the Flint River. I focused on the period starting in 2000 as relevant to evaluating to what extent there has been compliance with the criteria—or not—since their adoption in 1999. Non-

compliance started increasing after about 1970. Prior to 1970, non-compliance was relatively low.

59. The 1999 Guidelines specify three types of 1-day minimum flows for each month: (1) Criteria A: a 1-day minimum flow for each month that must be met *every single year* (*i.e.*, a flow below which flows must *never* drop); (2) Criteria B: a 1-day minimum flow for each month that must be met three out of every four years; and (3) Criteria C: a 1-day minimum flow for each month that must be met one out of every two years. Below, I discuss the trends in how many summer months (June 1-September 30) experience days with flows below these 1-day minimums. I define a month to be in non-compliance if flow on one or more days in that month was below the applicable 1-day minimum (i.e., of Criteria A, B, or C).

60. **Criteria A**: Non-compliance with Criteria A's 1-day minimum has increased dramatically from the pre-1970 period. At the Chattahoochee gage on the Apalachicola River, months in which non-compliance occurred went up by twofold when comparing the 1970-1999 period to the pre-1970 period. Non-compliance went up more than 10-fold when comparing the 2000-2015 period to the pre-1970 period. At the Bainbridge gage on the Flint River, the deterioration is also pronounced. Prior to 1970, not one single day ever fell below the Criteria A 1-day minimum, based on a record dating back to 1929. Since 2002, non-compliance occurred in more than one out of every three summer months, counting each and every summer, whether that summer was dry, normal or wet.

61. **Criteria B**: At the Chattahoochee gage on the Apalachicola River, summer months since 2000 routinely have been in non-compliance, with about three times as many summer months containing such days with flow below the minimum compared with the pre-1970 period. The situation is similar at the Bainbridge gage on the Flint River where summer

months since 2002 are about 2.5 times more likely to have days with flows below the 1-day minimum than in the pre-1970 record.

62. **Criteria C**: Non-compliance with the Criteria C 1-day is also evident. At the Chattahoochee gage, non-compliance occurs about 60% more frequently in the summer months since 2000 compared with the pre-1970 period. At Bainbridge, non-compliance occurs about 50% more frequently in the summer months since 2002 compared with the pre-1970 period.

B. The Basic Data Show That Rainfall Is Producing Less Runoff Than In Prior Decades

63. A simple but powerful way to assess hydrological change in a watershed over time is to calculate the "basin yield." Basin yield is the ratio of runoff (or streamflow) to rainfall for any particular time period, usually a year—one can think of it as the fraction of rainfall that becomes streamflow. Basin yield can be presented as either a fraction or a percentage. In the ACF, where climate conditions are stable, I would expect the basin yield to vary some year to year, but not to have a consistent upward or downward trend. However, if human activities are depleting runoff, the basin yield will show a declining trend. I used the Livneh gridded climate dataset and USGS gage data to calculate basin yield.

64. I found a declining trend in basin yield in the ACF Basin above the Chattahoochee Gage. In Table 4, below, I have calculated the basin yield for different periods, and a downward trend is apparent. I also calculated how much streamflow has declined compared to what it would have been if basin yield had remained stable (third column in Table 4). Given that climate has remained stable, this decline in basin yield is powerful evidence that Georgia's consumptive use is causing streamflow depletions.

Table 4. Basin Yield and Associated Change in Discharge at the Chattahoochee Gage, FL
Note that the calculations are by Water Year (WY). (Hydrologists use the water year (WY) running from 1 October through 30 September. Water year 1997, for example, runs from 1 October 1996 through 30 September 1997.)

Years	**Basin yield (annual average)**	**Approximate related decline in streamflow relative to Pre-1970 (cfs)**
1924-1970	0.329	--
1971-2013	0.316	850
1992-2013	0.289	2,500
2003-2013	0.270	3,900

65. Basin yield for individual drought years also shows a decline over time. (Table 5.) For example, before 1970, 1955 was the year with both the lowest average flow at the Georgia/Florida state-line (approximately 11,280 cfs) and the lowest basin yield (21.0%). Since the year 2000, there have been four years with lower basin yields than 1955 and three years with lower flows.

Table 5. Basin Yield Presented By Year, In Order of Lowest Basin Yield

Water Year	State-line Flow[a] (cfs)	Average Rainfall[b] (cfs)	Average Rainfall[b] (inches)	Basin Yield (%)
2012	7,608	54,844	43.3	13.9%
2002	8,681	51,612	40.7	16.8%
2000	9,132	49,510	39.1	18.4%
2008	11,998	60,880	48.0	19.7%
1955	11,283	53,729	42.4	21.0%
2011	10,515	49,751	39.3	21.1%
1956	12,476	59,002	46.6	21.1%
2007	10,667	48,054	37.9	22.2%
1941	12,256	54,125	42.7	22.6%
1935	13,867	59,084	46.6	23.5%
1951	12,155	50,438	39.8	24.1%
1988	13,142	53,529	42.2	24.6%
1981	12,661	48,759	38.5	26.0%
1999	13,458	47,895	37.8	28.1%
2006	14,214	50,095	39.5	28.4%
1986	14,303	49,375	39.0	29.0%
1931	17,125	51,455	40.6	33.3%
1954	18,696	46,834	37.0	39.9%

Notes:
(a) Average flows at the Florida-Georgia state line were computed for each water year from USGS gage 02358000.
(b) Average rainfall was computed from the data described by Livneh et al., (2013) for the area of the ACF Basin above USGS gage 02358000.

C. Data Show That the Upper Floridan Aquifer Is Being Depleted in Georgia, Reducing River Flows to Florida.

66. There is a close connection between groundwater and surface water in the lower Flint River Basin and in the lower Chattahoochee River Basin. Activities that deplete groundwater in this region also significantly reduce river flow. Basic data show that Georgia's water use is chronically depleting the Upper Floridan Aquifer, which is reducing river flow.

67. Groundwater levels are a key indicator of the condition of an aquifer. Several studies have evaluated groundwater elevations in the Upper Floridan Aquifer, each reporting declining trends in groundwater. I reviewed a publication by two USGS hydrologists, Lynn J.

Torak and Jaime A. Painter. Torak and Painter studied 10 monitoring wells in the Upper Floridan Aquifer and found that all 10 wells showed declining groundwater trends from the 1990s to 2002. (Langseth Expert Report (citing Torak and Painter, 2006), FX-795.) USGS scientists also studied 18 wells in the Upper Floridan Aquifer and found that 14 of those wells showed declining groundwater trends from 1972-2011. (Peck et al. 2013, JX-834.)

68. These groundwater declines are altering the natural hydrology of the lower Flint River Basin. Long reaches of streams that historically have received Upper Floridan Aquifer water as an inflow to the stream are being depleted, being deprived of base flows, and even running dry in places (Gordon *et al*., 2012, JX-54; Mosner, 2002; Figures 4 and 5). Streams that historically gain water from groundwater—called 'gaining streams'—are experiencing conditions where they actually lose streamflow to the groundwater, and are thus becoming 'losing streams.' These losing streams occur when groundwater levels drop below the elevation of the stream bed, causing the stream to seep into the ground.

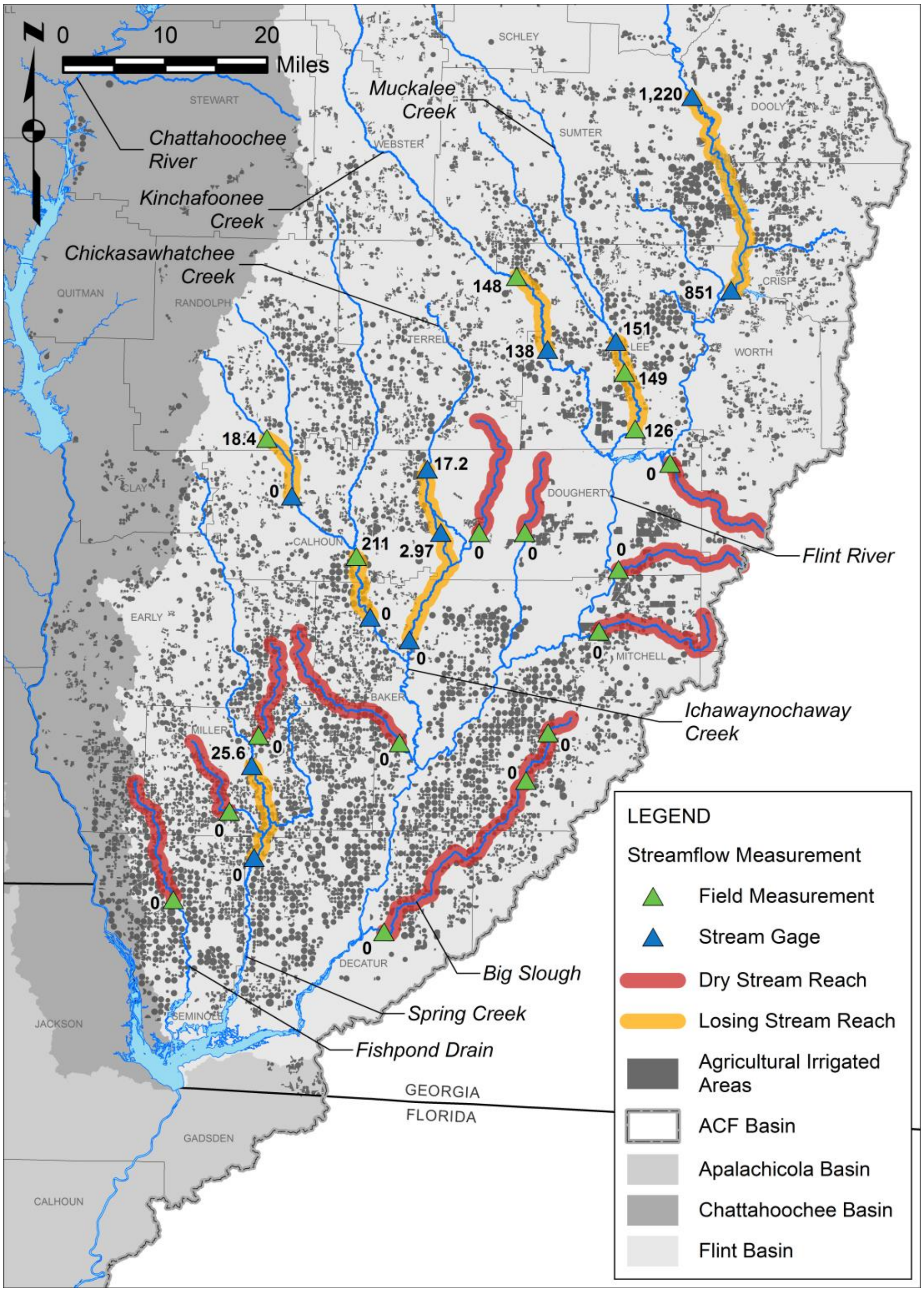


Figure 4. Losing Stream Reaches in the Flint River Basin Identified by Mosner (2002). This figure was prepared at the direction of Dr. Langseth for his February 29, 2016 expert report (FX-795 at 44) to reproduce Figure 6 in Mosner (2002), but using color highlighting to designate losing and dry streams.

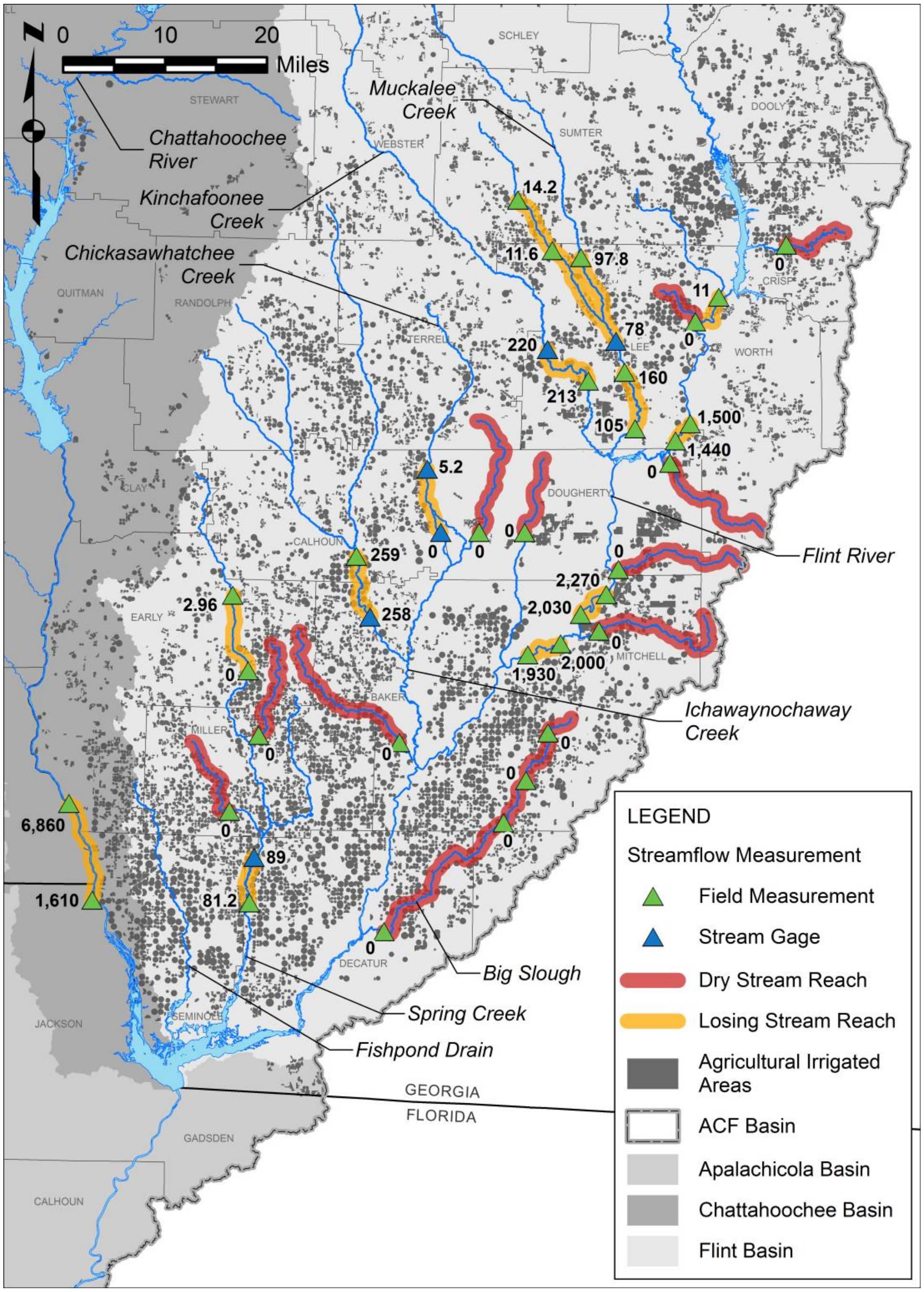


Figure 5. Losing Stream Reaches in the Flint River Basin Identified by Gordon *et al*. (2012). This figure was prepared at the direction of Dr. Langseth for his February 29, 2016 expert report (FX-795 at 45), adapting Figure 13 in Gordon *et al*. (2012), JX-54.

69. Such reversals of flow have been documented at Georgia's "blue-hole springs" in the Georgia portion of the ACF. These blue-hole springs are characterized by crystalline blue waters that emerge directly from groundwater to form beautiful pools. During periods of

drought, certain of these blue pools are being impacted by river water flowing into them, turning them brown. A recent USGS report describes this phenomenon as follows (Gordon *et al*., 2012. p. 16):

> "At a spring in Dougherty County south of Albany . . . groundwater levels declined below stream stage and allowed streamflow in the Flint River to invade the spring run and recharge the Upper Floridan aquifer. Under normal conditions this spring discharges to the Flint River and appears blue in color (fig. 10A); however, during the drought conditions of July 2011, river water flowed into the aquifer through the spring run, giving the water a muddy appearance (fig. 10B)."

(Gordon et al. 2012, JX-56 at Figure 10.)

Figure 6. Photographs of one blue hole spring under normal conditions and when drought has reduced it to a muddy puddle. (USGS, 2012, JX-54, at 17.)

70. Georgia EPD agrees with these fundamental points. In a September 6, 2011 memorandum on groundwater conditions in southwest Georgia and low flows in the Flint River, Georgia EPD hydrologist Dr. Wei Zeng declared that, in the Dougherty Plain area, which is essentially the same as the lower Flint River Basin, "groundwater pumping from the Upper Floridan Aquifer has a significant and quantifiable effect on surface water flow in the Flint River and its major tributaries." Dr. Zeng evaluated groundwater levels in 2011 and declared that "[e]ven when compared to 2007 and 2008 (the last year with strong La Nina), the two previous drought years, the lack of groundwater recovery this year was stunning." (Georgia EPD 2011, FX-82 at 1.)

VI. GEORGIA'S CONSUMPTIVE WATER USES ARE DEPLETING THE APALACHICOLA RIVER

71. The impacts from Georgia's consumptive uses are evident from the data and the analysis I describe above. To further evaluate the impacts of Georgia's consumptive use on Apalachicola streamflow, our team used two different tools to evaluate the issues from multiple perspectives, both of which show dramatic increases in Georgia consumption:

- "<u>Bottom-up" accounting of Georgia's water use</u>. First, it is important to quantify Georgia's use of water in the ACF. Dr. Flewelling undertook an accounting of Georgia's water use based on available records from Georgia, such as records of municipal water withdrawals and return flow, and metering information for irrigation. This "bottom-up" approach can only yield results consistent with the quality and comprehensiveness of data Georgia collects and maintains. I consider it to be an under-accounting for several reasons, including: (a) it relies on Georgia's data, which is incomplete and undercounts water use; and (b) it is not feasible to identify and quantify each individual water user, so certain water users are omitted entirely. In other words, this information is not a complete accounting of uses. Despite its limitations, this approach provides a reliable pattern of the growth of Georgia's consumptive water use over time, the distribution of water use during seasons, and the distribution of water use between categories like agricultural and other uses. It shows trends because that data is a sample of all uses.
- <u>Rainfall/runoff models</u>. Rainfall-runoff models calculate how much river flow will result from a given rainfall amount, given the consumptive use in the basin. These computer models are powerful tools that allow a reliable estimate of Georgia's total streamflow depletions based on trends in model

results over a period of decades. One characteristic of rainfall/runoff models is that they are more reliable and accurate over longer periods of time. In this case, I applied the USGS PRMS rainfall/runoff model, re-calibrated to low-flow conditions prior to the time (pre-1955) before Georgia's consumptive use started escalating. This enables PRMS to be run with recent rainfall data to see what the flows would have been in the absence of the modern increases in Georgia's consumption. I compared the PRMS results from two other studies which also applied rainfall/runoff models to the Georgia portion of the ACF. The results of these three approaches were similar, giving me confidence in the PRMS depletions estimate.

72. Both of these tools have certain limitations, which I have accounted for in this testimony. By combining the results from the rainfall/runoff models with information about the patterns and timing of water consumption from the "bottom-up" accounting approach, I was able to develop a reliable estimate of the streamflow depletions from Georgia's consumptive use on a year-by-year and even on a peak monthly basis.

73. Below, I describe the "bottom-up" accounting and the rainfall/runoff models in more detail and explain the methodology that I used.

A. Even a Bottom-Up Accounting of Georgia's Water Use Shows That Georgia's Consumption in the ACF Basin is Many Thousands of cfs in Summer Months.

74. Dr. Flewelling conducted a thorough analysis of Georgia's water use using an accounting approach—identifying and summing available water data—and I draw from his analysis here, as I did in my February 29 expert report. (Flewelling Feb. 29, 2016 Expert Report, FX-786.) Between 1970 and the present, Georgia's population and irrigated agriculture within

the ACF Basin have surged. This growth in people and irrigation has led to a predictable increase in consumptive water use and streamflow depletions.

Table 6. Georgia's Increased Population, Irrigated Acres, and Consumptive Water Use in the ACF Basin, Based on the Accounting Approach

Year	1970	2011
Population	1.85 million	5.37 million
Irrigated acres	73,500	>776,000
Consumptive water use—peak month	<450 cfs	>4,500 cfs

75. As described above, Dr. Flewelling has attempted to quantify Georgia's consumptive water use by employing a bottom-up accounting method that relies upon the limited data reported by Georgia. This approach necessarily understates Georgia's actual water use, but is nevertheless useful for evaluating macro-level trends. Table 6 compares consumptive use in the Georgia portion of the ACF Basin across two periods: 1970—*i.e.*, before the widespread proliferation of irrigation in Georgia—and 2011, a drought year with high water use. Peak monthly consumptive water use in the Georgia portion of the ACF, as estimated by Dr. Flewelling in his February 29, 2016 report, has increased by approximately 1000 percent from 1970 to today, reaching more than 4,500 cfs in drought years, even using these conservative assumptions.

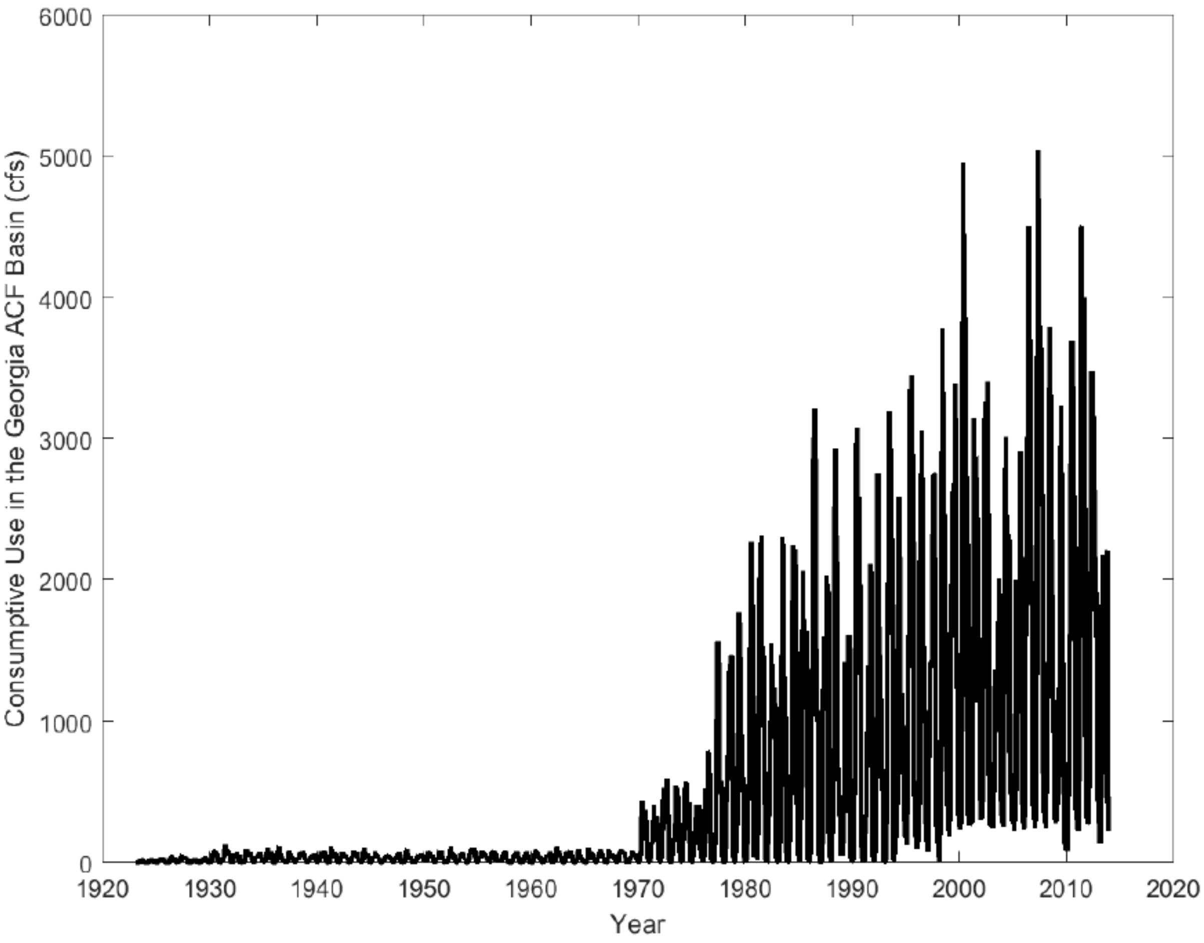


Figure 7. Total Monthly Consumptive Water Use in the Georgia ACF Basin from 1923-2013 Using Conservative Assumptions. Source: Flewelling Expert Report (2016) (Figure 2 from Hornberger Feb. 29, 2016 Expert Report)

76. I have reviewed and am relying on Dr. Flewelling's consumptive use estimates. Dr. Flewelling's estimates are contained in his Georgia Consumptive Use Spreadsheet, which he created to interpret, calculate, and summarize—using consumption data compiled by Georgia state agencies and academic institutions—Georgia's overall consumptive water use from 1970 to 2013 across several different use categories. Those uses include agricultural, municipal and industrial uses; inter-basin transfers; and evaporative loss from small impoundments and state and federal reservoirs. (Flewelling 2016, FX-641.) I address each of these briefly below.

77. <u>Agricultural water use</u>. Irrigation, the single largest consumptive water use in the Georgia portion of the ACF basin, has increased from under 75,000 acres in 1970 to more than 825,000 acres in 2014. (Flewelling Expert Report.) Much of this increase has been driven by center-pivot irrigation technology. Dr. Flewelling's estimates of agricultural water use are based on two principal values—(a) irrigated acres (the total *area* on which farmers actually irrigate) and (b) irrigation depth (the *amount* of water farmers apply to irrigate crops over a particular area). Dr. Flewelling's expert report provides further detail on the methods used to estimate irrigated acres and irrigation depths, which I have reviewed and rely upon here. Using conservative data known to understate Georgia's water use, I found that during summer months in recent drought years, agricultural water use has been nearly 4,000 cfs.

78. As described in detail in his expert report, Dr. Flewelling's irrigation depth calculations are based on irrigation depth data in Georgia's Agricultural Metering Database, a 2015 database prepared by the Georgia Department of Natural Resources compiling information on permitted metered withdrawals throughout the ACF Basin. I understand that Georgia provided new information on the irrigated acreage data after I submitted my February 2016 expert report. Dr. Sunding's adjustment of his irrigation depths estimates result in marginally lower irrigation depths (see Testimony of Dr. Sunding). I evaluated the potential impact of including those values in the consumptive use estimates from Dr. Flewelling and found the impact to be insignificant. Furthermore, as explained below, the potential impacts of Georgia's revised irrigation depths on calculated streamflow depletions are even smaller. As a result, Georgia's revised irrigation depths do not change my opinion that Georgia's consumptive use in the ACF Basin is significantly impacting flows to the Apalachicola. In addition, the consumptive use estimates used in my February 29 expert report and in this testimony are based

on a very conservative accounting method. Thus in any event Georgia's consumptive use is actually significantly higher, as explained below.

79. Drawing on data regarding surface and groundwater permit locations from Georgia EPD's 2015 Agricultural Permit Database—a 2015 database maintained by the Georgia Department of Natural Resources compiling data relating to the source and distribution of agricultural water permits in Georgia—Figure 8 illustrates the spatial distribution of agricultural permits in the Georgia portion of the ACF Basin, showing a clear concentration in the lower Flint and Chattahoochee River Basins.

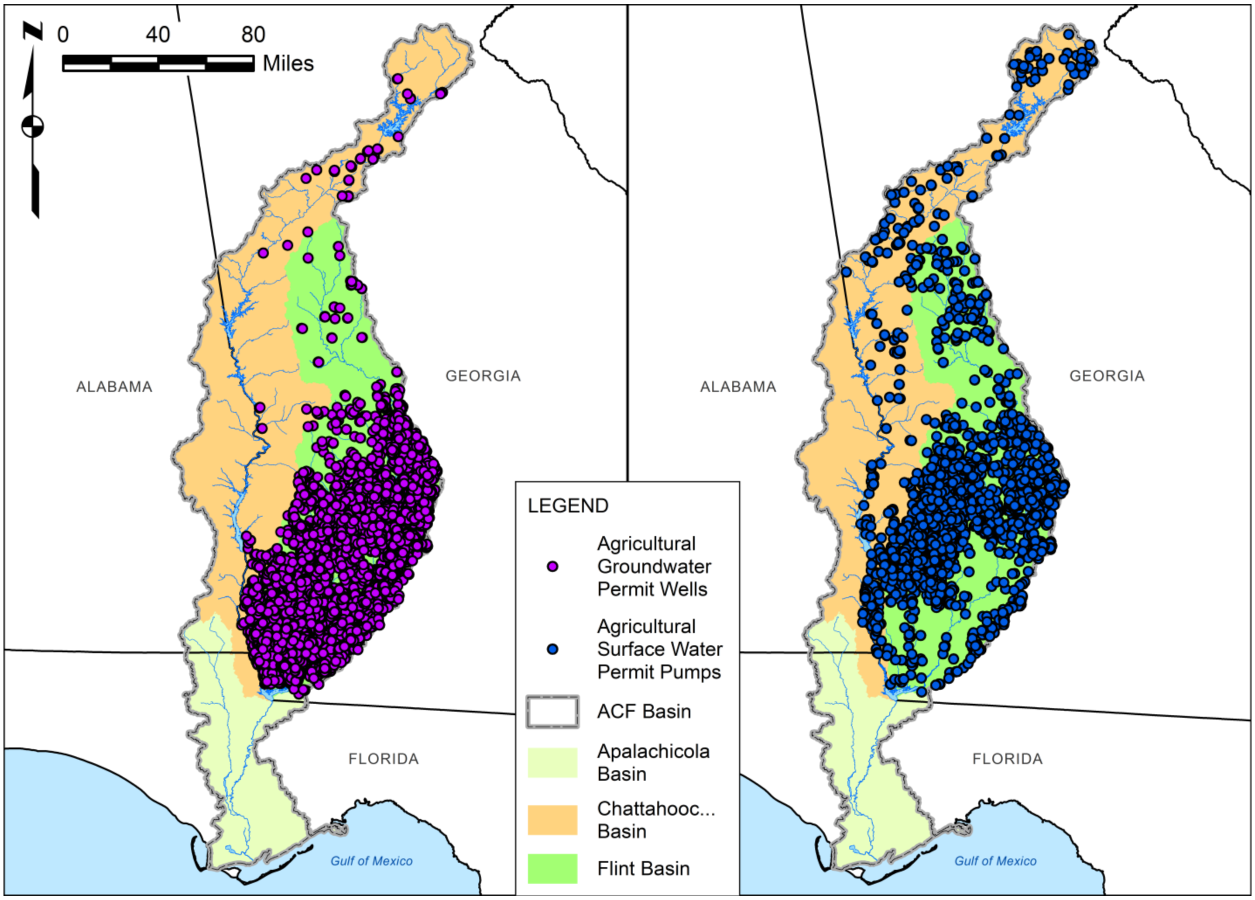


Figure 8 Locations of Permitted Agricultural Withdrawals in the Georgia ACF Basin (Flewelling Expert Report Figure 2.2)

80. Municipal and industrial use. This category includes water for homes, cities, and businesses. From 1970 to the present, population in the Atlanta Metropolitan Statistical Area

grew from around 1.85 million to 5.61 million (Hornberger Feb. 29, 2016 Expert Report). This population increase has driven consumptive use increases. Using Georgia's self-reported and limited data, municipal and industrial consumptive water use during the summer months of recent drought years has consistently been well over 600 cfs .

81. Man-made impoundments. Farms in the Georgia portion of the ACF Basin are blanketed with irrigation ponds that increase evaporation, resulting in streamflow depletions. Dr. Flewelling's estimate of net evaporative loss from these farm ponds approaches 400 cfs during summer months in drought years. Dr. Flewelling estimated that, as of 2014, there were more than 20,000 small impoundments covering a combined area of more than 64,500 acres in the Georgia portion of the ACF Basin. The Georgia Water Resources Institute (GWRI) of the Georgia Institute of Technology in Atlanta estimated in its October 2012 draft *Unimpaired Flow Assessment for the ACF Basin* that evaporation from small impoundments exceeds 1,000 cfs in some months, with a 12-month running average of about 600 cfs in recent years. (GWRI 2012, FX-534 at Appendix B, 198-211.) Exhibit FX-534 is a true and accurate copy of the draft document that the Georgia Institute of Technology produced and which I reviewed and relied upon in forming my opinions in this case. In addition, non-federal reservoirs in the Georgia ACF Basin, such as the Morgan Falls Reservoir just north of Atlanta, account for net evaporation of over 100 cfs in many summer months. (Flewelling Expert Report at S-5.)

82. Inter-basin transfers. Despite the adverse impacts of Georgia's water use on streamflow in Georgia and on the Apalachicola River, Georgia exports substantial water volumes from the ACF Basin to areas outside the basin. Georgia's data on inter-basin transfers show annual net exports approaching 100 cfs in recent years (Flewelling Expert Report).

B. I Used the PRMS Rainfall/Runoff Model to Quantify the Streamflow Depletions That Georgia's Consumptive Use Is Causing in Drought Years

83. I used rainfall/runoff models to estimate the overall magnitude of streamflow depletions caused by Georgia's water use. Rainfall/runoff models are widely used in hydrology, as described in numerous hydrology textbooks, including my own, *Elements of Physical Hydrology*. They are well-suited to address the issues in this case, a point acknowledged by Georgia's hydrology expert, Dr. Philip Bedient (Bedient Dep. Tr. 545:16-546:2), and in Dr. Aris Georgakakos' 2012 draft *Unimpaired Flow Assessment for the ACF Basin* (GWRI 2012, FX-534 at 193 (stating that rainfall-runoff models "can be calibrated based on early hydrologic periods (when these [human] effects were negligible) and subsequently used to generate hydrologically consistent UIFs [unimpaired flows] for recent periods"; the process Dr. Georgakakos is describing in general is exactly what I did here).

84. The rainfall-runoff model that I used is called PRMS (pronounced "Prims"). The USGS developed PRMS and has used it to model ACF Basin hydrology. Similar to other rainfall/runoff models, PRMS takes climate conditions—*e.g.*, precipitation and solar radiation—as model inputs, and performs a series of calculations, as illustrated in Figure 9. These calculations are based on fundamental hydrological principles and are used to determine how much water is evaporated (*e.g.*, from soil or surface water bodies) or transpired (through plants), stored in soil, returned to groundwater, or passed on to streams.

85. My PRMS modeling results show depletions of approximately 3,000 to 4,000 cfs on average over June to September months in low-flow years during the 2000 to 2012 period I evaluated, as presented below in Table 7. This streamflow depletion result is similar to the result of the basic data analysis I presented above showing that flow from Georgia to the Apalachicola River was approximately 3,500 to 4,000 cfs lower in the modern drought of 2011 to 2012

compared to the drought of 1954 to 1955. I explain the process I used to interpret my PRMS modeling results below.

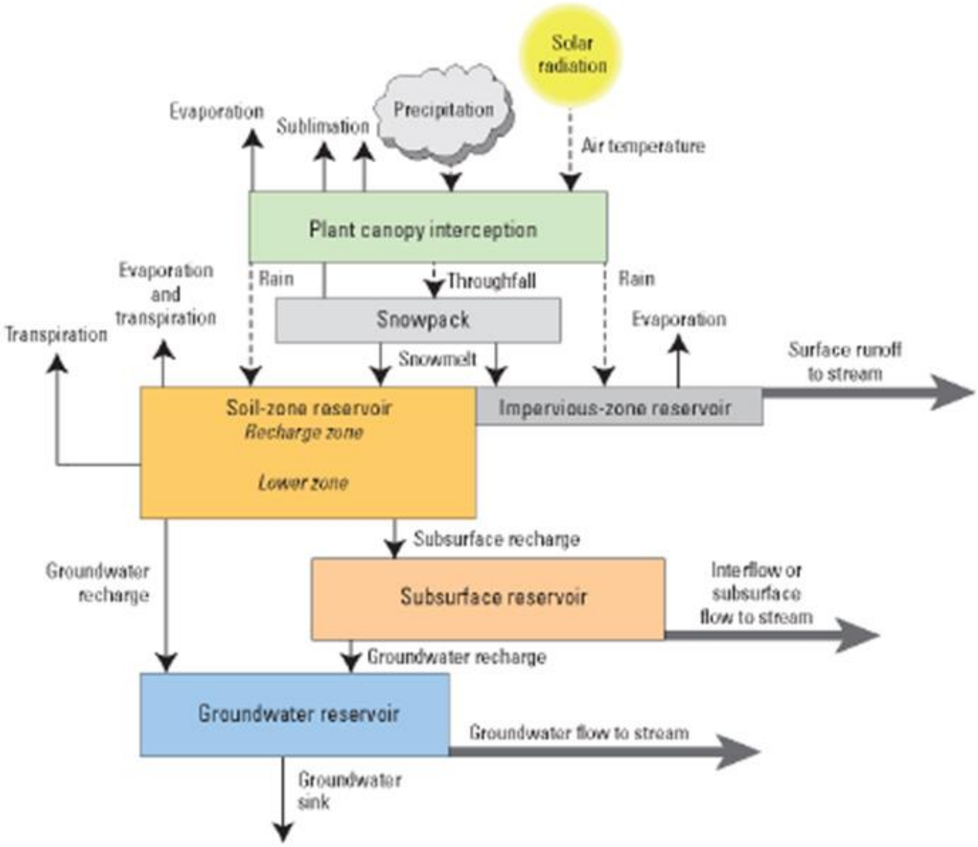


Figure 9: Diagram of the Processes Simulated in PRMS. Reproduced from LaFontaine *et al.* (2013) (JX-82).

86. I calibrated the PRMS model to match measured river flows at many USGS gages in the Georgia ACF for the period before 1955—a period before Georgia's consumptive uses escalated. Calibration involves adjusting the model with calculated flows from the model to ensure it appropriately predict flows as different variables are adjusted. The calibration process is described in more detail in my February 2016 Expert Report.

87. I then used this calibrated version of PRMS to forecast what the flows would have been at the Chattahoochee Gage in Florida near the state line absent increased consumptive uses

in Georgia in years following 1955. Differences between river flow measured at the Chattahoochee Gage (which includes the effects of consumptive use of water in the Georgia ACF) and the modeled values (which calculate what streamflow would have been with minimal human consumptive use) provide an estimate of the streamflow losses to Florida due to human consumptive use in Georgia. I then processed these raw model output to account only for streamflow depletions caused by Georgia's water use (and not by Florida's or Alabama's water use).

88. I evaluated the PRMS model run results produced with my expert report in February 2016 and found that average depletions from 1953 to 2013 are around 1,500 cfs higher than the period before 1953. This is a long-term average annual increase for the years since 1953. Since consumption did not start to significantly escalate until about 1970, actual depletions in recent years would be far greater than 1,500 cfs. This long-term average annual increase enables ready comparison with results from other rainfall/runoff models. (Also, this long-term increase includes the depletions from the federal reservoir system, *e.g.*, evaporation from Lakes Lanier and Seminole. I did not remove that effect before comparing to the other rainfall/runoff models because those models included those reservoir effects too. I address that effect below.)

89. I compared these PRMS results with results from other rainfall/runoff models that are widely accepted and used by the hydrological community, including the Variable Infiltration Capacity (VIC) model and recently published results by Jaramillo and Destouni. Florida expert Dr. Dennis Lettenmaier ran the VIC model and presented the results in his February 2016 expert report, using several different gridded climate datasets. The methodologies that were used to generate these datasets have been widely used throughout the scientific community. These

datasets differ mainly based on the selection of gages, the gridding technique, and spatial resolution of the grid. The comparable results from the VIC model at the Chattahoochee gage for the period since 1953 for these three climate datasets are presented in Table 7. Like Livneh, discussed above, SWM is a highly respected, gridded hydrolclimatological dataset based on observed and modeled variables to generate hydroclimate data for the contiguous United States. This model was generated at the University of Washington in 2006 and is based on generally accepted scientific principles and methods; it is commonly used by experts in my field to assess hydroclimate data. SWM 1/16 is a model based on the SWM model, prepared for this litigation at the direction of Dr. Lettenmaier (one of the principal authors of the original SWM model, as well), using a more finely-grained grid than the SWM dataset. As with SWM, this dataset was generated using generally accepted scientific principles and methods.

90. The paper by Jaramillo and Destouni (2015) in the prestigious journal *Science* examined the effect of irrigation and flow regulation by humans on the hydrology of 100 large basins across the world, including in the Georgia portion of the ACF Basin. Jaramillo, F. and Destouni, G. "Local flow regulation and irrigation raise global human water consumption and footprint." *Science* 04 (2015): 350 – 6265. DOI: 10.1126/science.aad1010, FX-619a and FX-619b. As I explained in my February 2016 expert report, I reviewed Jaramillo and Destouni's results and used their findings to calculate the average reduction in water in the ACF Basin due to Georgia's consumption over the period they examined (1955 to 2008), and compared it to an earlier period (1901 to 1954).

91. The long-term average increase in depletions from PRMS, VIC, and Jaramillo and Destouni are remarkably consistent, as reflected in the table below:

Table 7. Long-Term Average Increase in Depletions since 1953 at the Chattahoochee Gage on the Apalachicola River in Florida

Model	Depletion (cfs)
VIC (Livneh)	1,131
VIC (SWM)	2,184
VIC (SWM 1/16)	1,014
PRMS	1,489
Jaramillo & Destouni	1,346

Average Value	1,433

92. Hydrologists often use the results from comparable models to assess the reliability and accuracy of model results. The arithmetic mean depletion for PRMS, VIC, and Jaramillo and Destouni model runs is 1,433 cfs. The fact that PRMS depletions are very close to the average of other comparable models, and the high degree of consistency among these models, gives me a high degree of confidence that the PRMS model is providing reliable and accurate estimates of depletions in the Georgia ACF.

93. I then ran the PRMS results for the Chattahoochee Gage through the ResSim model. ResSim has a number of shortcomings, which I explain in below. I still chose to use it as a conservative approach to account for the incremental evaporation from the reservoirs and the Corps' operational rules that give minimum flow releases.

94. Finally, I took the time pattern of consumptive use from Dr. Flewelling as valid although I consider the total volumes to be underestimates. I take the residuals from PRMS as the best estimates of volumes of consumptive use so I used Dr. Flewelling's time pattern to scale the PRMS depletions and distribute them across years and months since 1954. Table 8 below show the results of this approach, and presents my best estimates of streamflow depletions caused by Georgia's water use in recent drought years.

Table 8. June-September and Peak-Month Depletions in the Georgia ACF from PRMS Run with ResSim

	June-September Average Depletions (cfs)		Peak-Month Depletions (cfs)
Year	**PRMS-ResSim**		**PRMS-ResSim**
2000	3,700		5,000
2001	2,800		3,300
2002	3,700		4,100
2006	4,100		5,500
2007	4,400		5,400
2008	3,300		4,600
2010	4,000		5,100
2011	4,200		5,300
2012	3,400		3,900

95. As I noted in in my February 2016 report, the PRMS results indicate that depletions in the Georgia portion of the ACF increased by several thousand cfs from 1970 to the present. I found that there is a clear upward trend in the model estimates of flow depletions that coincides with the growth in Georgia's consumptive use. The Table 8 values detail results reported by each of Dr. Flewelling and me, and employs simple math to help illustrate that PRMS provides the best estimate of Georgia's consumptive uses.

VII. PUMPING WATER FROM THE UPPER FLORIDAN AQUIFER DEPLETES STREAMFLOW

96. When Georgia removes water from a stream or reservoir on a river, that withdrawal reduces streamflow directly, and 100% of such water use is a streamflow depletion if that water is not returned after use.

97. Groundwater is different. Hydrologists commonly analyze the relationship between groundwater pumping (mainly through agricultural irrigation) and streamflow depletions by focusing on a ratio called the "impact factor." An impact factor is represented as a fraction or percentage.

A. An Impact Factor Describes the Effect Groundwater Pumping Has on Streamflow Pumping

98. I conclude that approximately 90% of groundwater removed through agricultural pumping eventually becomes a streamflow depletion. But the immediate (same year) impact on streamflow is calculated differently: a lesser percentage of groundwater removed by agricultural pumping reduces streamflow within the year it was pumped. According to a study that Georgia's expert, Dr. Panday, conducted in 1998, the same year impact of groundwater pumping on streamflow depletion in the ACF is 60 percent (0.60): for every 100 gallons of groundwater removed from the Upper Florida Aquifer, local streamflow is reduced by 60 gallon in the same year. (More than 60% impact could occur over a longer period.) I discuss these groundwater impacts from pumping, specifically for, and limited to, the Upper Floridan Aquifer only, in this section.

99. <u>Long-Term Impact Factor</u>. Fundamental hydrologic principles support my opinion that the total long-term impact factor in the Upper Floridan Aquifer is 90% or higher. My opinion is consistent with a study by the Georgia Geological Survey, a state agency, which concluded that long-term impact factors in the ACF Basin are nearly 1.0. (Hayes, L.R., *et al*. Georgia Dept. of Natural Resources (GADNR), Environmental Protection Division (GA EPD) 1983. "Hydrology and Model Evaluation of the Principal Artesian Aquifer, Dougherty Plain, Southwest Georgia." Georgia Geologic Survey. Bulletin 97.)

100. Short-Term Impact Factor. In 1998, Georgia's expert, Dr. Panday estimated the short-term impact factor in the ACF was 0.60 or higher. (HydroGeoLogic 1998, FX-594 at 23.) In 2012, Georgia's Environmental Protection Division ("EPD") used the Jones and Torak model to perform a simulation of 2011 pumping conditions, which resulted in an impact factor of 47%. (GADNR, Zeng Dep. Tr. (February 18, 2016), Ex. 78, FX-629 at 4 (dividing surface water reductions attributable to groundwater withdrawals (202 cfs) by total agriculture water pumping (427), where 202/427 = 0.47 or 47%).) Dr. Langseth relied on the Jones and Torak model calculated a short-term impact factor of 41%, which he understood would necessarily understate the rate at which groundwater withdrawals reduce streamflow. (Langseth Report at SS-7, SS-8, 40, 51-52, E-9, E-10.)

101. Both Dr. Langseth and I have reviewed the respective modeling work by Dr. Panday and Georgia EPD. We also have compared the range of these impact factors—*i.e.*, 41% to 60%—and their corresponding streamflow depletions with results from the rainfall/runoff models. For a number of reasons, I agree with Dr. Langseth that the short-term impact factor ranges from at least 41% to a more realistic, yet still conservative, 60%. Langseth Dep. Tr. 1161:11-15 (August 18, 2016); Langseth Report, Appendix D at D-5.)

102. I rely on 0.60 as a conservative estimate of the actual short-term impact factor. For several reasons, however, I believe use of the 0.60 impact factor likely understates the impact of groundwater withdrawals on streamflow depletions. A factor of 0.60 begins to approach but does not account for the large streamflow declines observed in the raw data. Also, the stream system in the lower Flint River Basin is very sensitive to groundwater pumping: local springs in the ACF often run dry, and the flow from groundwater to surface water often reverses with surface water flowing into the aquifer rather than water from the aquifer flowing to the

surface as normally occurs. An impact factor higher than 0.60 would more accurately reflect the very responsive nature of this interconnected groundwater and surface water system. I agree with Dr. Langseth that a 0.41 impact factor significantly understates the real impacts observed in the hydrological data.

B. The Impact of Groundwater Pumping on Streamflow Depletions Increases During Multi-Year Droughts

103. The short-term impacts of groundwater pumping on streamflow during multi-year droughts increase as the drought progresses. So in a drought that spans three years, the impact factor is greater in year three than in year one.

104. This relationship follows from basic mass-balance principles. Water pumped out of a groundwater aquifer comes from either reduced streamflow, increased recharge in the aquifer, or reduced storage in the aquifer. If reduced storage is not replenished between growing seasons, an aquifer is in a depleted condition, with lower water levels, at the beginning of a second or third drought year.

105. The 2011-2012 drought that Georgia experienced illustrates the aggravated impacts of multi-year droughts. The year 2009 was a relatively wet year: approximately 25% of the precipitation in the Lower Flint River Basin ended up recharging the Upper Floridan Aquifer. The year 2010 was somewhat drier: the recharge rate in the Upper Floridan Aquifer was approximately 21 percent. A recharge rate is the proportion of precipitation that percolates to the aquifer. Severe drought commenced in 2011, however, and continued through much of 2012. As a result, recharge rates fell to 13% and then 10%, respectively. In addition to experiencing very low recharge rates, the Upper Floridan Aquifer was pumped intensely during that period: agricultural withdrawals consumed fully 45% and 50% of the diminished recharge during 2011 and 2012, respectively. Accordingly, groundwater levels declined precipitously.

106. In sum, multi-year droughts impose particularly significant stresses on groundwater levels. And as aquifer levels decline, so does the aquifer's ability to provide baseflow to rivers and streams, which run increasingly low—and even dry as occurred in Spring Creek. Because streamflows are so dependent on baseflow during dry periods, pumping-reduction or elimination measures should be undertaken to minimize the impacts on groundwater levels.

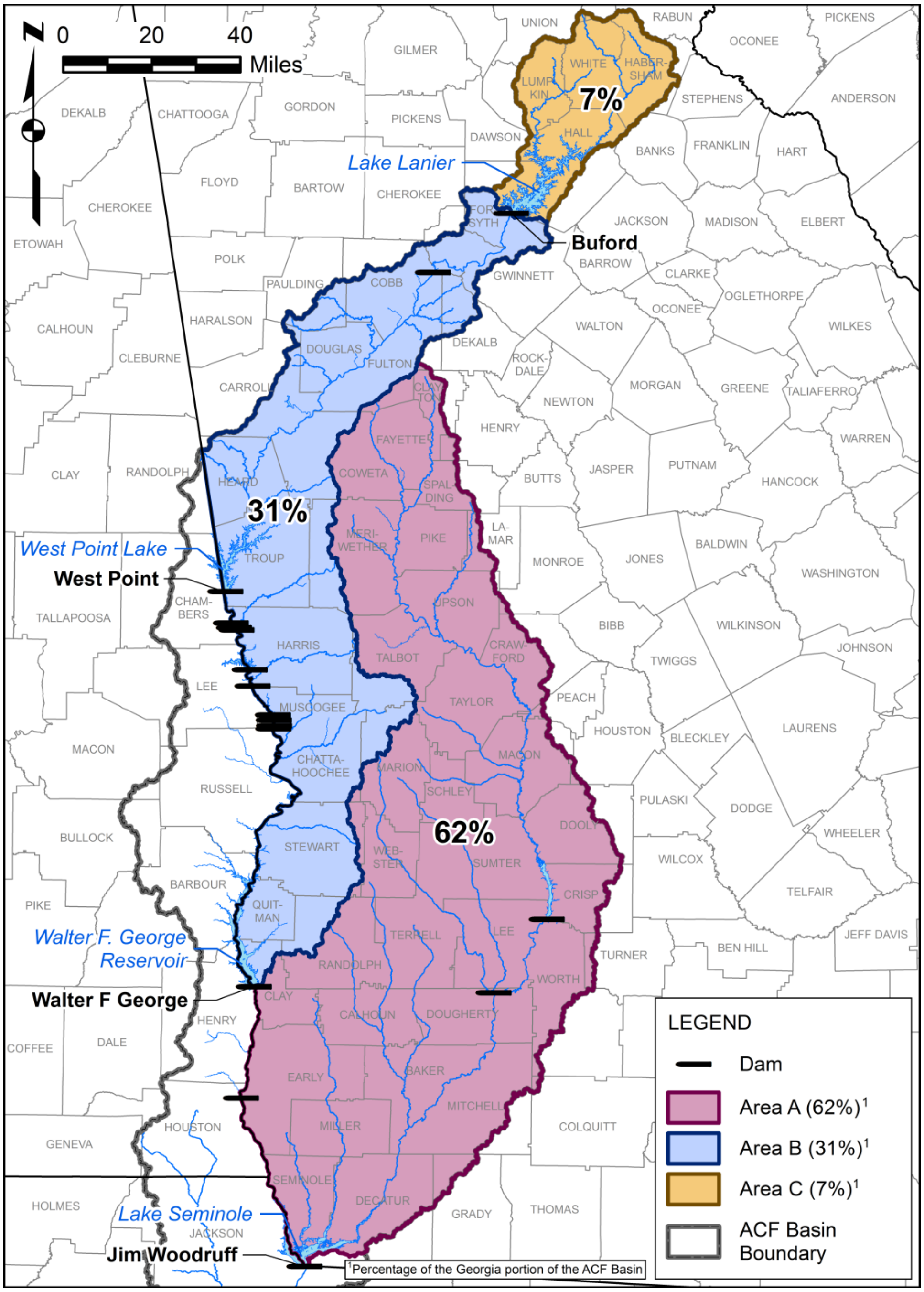
VIII. GEORGIA WATER CONSERVATION MEASURES WOULD SIGNIFICANTLY INCREASE APALACHICOLA RIVER FLOWS

107. A remedy in this case requiring Georgia to conserve water during drought summers would increase flow on the Apalachicola River. Nearly all of the water Georgia conserves during drought summers would become flow on the Apalachicola River during the summer in which it is conserved.

A. The Army Corps Operates the Dams in Such a Way That Conserved Water Would Benefit Florida With Additional Flow on the Apalachicola River

108. The United States Army Corps operates five federal reservoir projects on the Chattahoochee River, including Lake Seminole at the confluence of the Chattahoochee and Flint Rivers. The system includes, from upstream to downstream: Buford Dam (which impounds Lake Lanier); West Point Dam and Lake; W.F. George Dam and Lake; George Andrews Dam; and Jim Woodruff Dam (which impounds Lake Seminole) (Figure 2).

109. As Dr. Shanahan explains in his testimony, the Georgia portion of the ACF Basin falls into three categories based on which dams (if any) regulate flow:



[1]Percentage of the Georgia portion of the ACF Basin

Figure 10. Map of ACF Basin in Georgia Showing Areas A, B, C

110. Figure 10 was prepared at my direction using geographic information system (GIS) data to illustrate the Georgia potion of the ACF Basin that is unregulated (62%), regulated by dams that operate in pass-through mode during the summer (31%), and regulated by Buford Dam (7%).

111. In sum, water conserved in the 93% of the Georgia portion of the ACF Basin that lies downstream of Lake Lanier (i.e., the sum of Areas A + B) would make it to the Apalachicola River during the summer when it is conserved. Nearly all of the conservation measures Georgia would implement in a remedy scenario would occur within this area.

112. The conservation scenarios described by Dr. Sunding in his testimony return approximately 1,500 to over 2,000 cfs of flow to rivers and streams throughout the Georgia ACF Basin during the peak month of water use in a drought year. Based on the locations in the basin where these savings occur, the vast majority of this water (at least 98%) will reach Florida during summer months. The break-down of where these increased flows will occur under the 2,000 cfs scenario is as follows: 1) 1,740 cfs from Area A; 2) 227 cfs from Area B; and 3) 33 cfs from Area C.

113. Thus, I know from Dr. Shanahan's analysis of how the reservoirs operate that approximately 98% of water conserved under Dr. Sunding's remedy scenario will show up as increased flow on the Apalachicola River during the summer it is conserved.

B. That Additional Flow Would Help Ensure That The River Would More Frequently Meet Relevant Federal Criteria

114. As discussed, above, summer flows during dry and drought years are chronically below the U.S. EPA and FWS 1999 Guidelines at both the Chattahoochee gage on the Apalachicola River and Bainbridge gage on the Flint River. One common measure of whether mitigation measures are successful is whether they improve compliance with relevant criteria. This approach is routinely employed in my discipline, and frequently demanded by regulatory bodies. I evaluated the extent to which returning flow through Georgia conservation measures to the Chattahoochee and Bainbridge gages would close the chronic gap with the 1999 Guidelines. I selected Criteria A (the 1-day, low-flow criterion that is never to be failed) and B as the most

relevant criteria against which to measure the benefits of the remedy, since those are the lowest-flow criteria. I determined that the flow improvements associated with the conservation measures that Florida is seeking would dramatically improve compliance with Criteria A, and otherwise would show marked improvement with respect to Criteria B.

115. Restoring 1,500-2,000 cfs flow in the river system in drought years at the Chattahoochee gage results in dramatic improvements and ensures that flows meet the U.S. EPA and FWS criteria much more frequently. Specifically, with an additional 1,500 cfs of flow at the Chattahoochee gage, only 1 out of every 5 summer months would contain a low flow below the Criteria A 1-day minimum. Presently, more than 1 out of every 2 summer months experiences such low flows. This is a major improvement, even though low flows still would be more frequent than in the historic record. Prior to 1970, such low flows occurred in only 1 of 20 summer months. The addition of 2,000 cfs would close the gap further, resulting in a condition where the Criteria A 1-day minimum is violated in only 1 out of 10 summer months, much closer to the historic norm.

116. Compliance with Criteria B would also be improved by such additional flows. 1,500 cfs would reduce summer months with days below the Criteria B 1-day minimum from 78% to 66%; 2,000 cfs would reduce such non-compliance to 55%.

117. Restoring 1,000 cfs at Bainbridge results in dramatic improvements. Specifically, with an additional 1,000 cfs of flow at Bainbridge, Criteria A would be met in ***98%*** of summer months. While not the 100% compliance from the pre-1970 period, this is much better than what is happening now where 1 out of every 3 months is in non-compliance. Almost 2 out of 3 summer months would satisfy Criteria B compared with only 1 out of 3 under current conditions.

This is moving closer to the historic norm when only one out of four summer months failed Criteria B.

C. I Used Reservoir Models to Validate My Findings That Conserved Water Would Yield Significant Benefits to Florida

118. I understand from Dr. Shanahan's analysis and the manner in which the Army Corps operates the reservoirs that the water Georgia conserves in a remedy will nearly all make its way to the Apalachicola River as additional flow during the particular summer in which it is conserved.

119. I used reservoir models to further explore this finding. In the simplest sense, a reservoir can be conceptualized as a bucket that has water flowing into the top and a valve at the bottom that can be controlled to let prescribed amounts of water out. Reservoir models simply take the amount of water coming in, predict the amount of water going out (according to a set of release rules, *i.e.*, how much to open the outlet valve), and then calculate the change in water volume within the reservoir (as input minus output, factoring in evaporation). This relatively simple conceptual model is the basis for all reservoir models.

120. I analyzed the following two models but found that they did not faithfully represent the reservoir operations for a remedy scenario.

- <u>HEC-ResSim (ResSim)</u>. ResSim is an Army Corps computer model that simulates operation of the ACF Basin reservoirs and dams for planning purposes. When I compared ResSim models runs to the observed data, I noticed a significant problem. ResSim under-predicts the release of water from storage in summers of dry years. This results because ResSim calculates the minimum release the Army Corps is allowed under its operating rules, but the data show that the Corps often exercises its discretion to release more than minimum flows. (See Testimony of Dr. Peter Shanahan.) In sum, ResSim under-predicts the increased flow that Florida would receive from Georgia conservation measures.

- <u>Data-Driven ResSim</u>. I developed the Data-Driven ResSim model as an improvement on the basic ResSim package. The Data-Driven ResSim model differs from the basic ResSim model in that it uses reported historical data for inflow and outflow, instead of the unreliable synthetic hydrographs upon which the basic ResSim model is typically run by the Corps. I saw from the Data-Driven ResSim model results that this model was still not capturing significant aspects of the Corps' discretion in passing flows to Florida.

121. The limitations of the ResSim model and the Data-Driven ResSim model led me to develop what I call the Lake Seminole model. The Lake Seminole model is run with observed reservoir storage information from all relevant Corps dams as well as historical inflow/outflow data from the Corps so that it replicates the Army Corps' actual operations as closely as possible. The Lake Seminole Model incorporates the ResSim operating rules for Lake Seminole. Georgia has criticized the Lake Seminole Model as results-oriented. I strongly disagree with that criticism.

122. A model is a tool, and if you do not have the right tool, you cannot do the job. The ResSim and Data-Driven ResSim models were not the right tools for the job here, namely, to determine whether, in light of the Corps' operation of its dams in the ACF Basin during summer months in dry years, a consumption cap would benefit Florida during summer months in dry years. To answer that question, it was necessary to find the right tool—a model that accurately

reflected Corps operations during these dry summer months. That is all the Lake Seminole model is. It uses a standard step-ahead approach to ensure that the Corps' actual exercise of discretion to provide more than the minimum flow is captured—something ResSim fails to do. It then applies that full characterization of discretion to estimate what the Corps would do in the presence of more water, such as from Georgia conservation. The Lake Seminole model is a better tool than ResSim to model what would happen if Georgia conserves water in the ACF Basin.

123. The Lake Seminole model confirms that virtually all of the water that Georgia conserves by implementing a remedy will become flow in the Apalachicola River in the summer it is conserved. I evaluated a range of various conservation measure scenarios using the conservative bottom-up accounting approach and presented the results in my February 29, 2016 expert report and accompanying materials. For instance, I considered a scenario that involved a reduction about approximately 50% of agricultural water use and small impoundments, as well as elimination of interbasin transfers. (This scenario is described in more detail along with the modeling results in my expert report.) I also considered the scenario where all water using the "bottom-up" accounting approach is conserved. I believe the scenarios of 1,500 to over 2,000 cfs of measures Dr. Sunding proposed in testimony falls somewhere between the two model runs I just discussed. Therefore, I am confident that it will produce substantial flow benefits to Florida during low flow times of drought years.

124. As discussed above, at my direction, Dr. Flewelling considered the possible effects of using slightly lower irrigation depths (the amount of water applied to water unit area of crops). I spoke with Dr. Flewelling about his approach, and reviewed his findings. I also considered the potential implications for the range of modeling scenarios I ran and discussed in

my February 29, 2016 expert report. I estimate the impacts and found them to be insignificant because they would be below a few percent.

IX. FUTURE GROWTH OF GEORGIA'S CONSUMPTIVE USES WILL CAUSE EVEN GREATER REDUCTIONS IN FLOW TO FLORIDA, UNLESS CAPPED

125. If Georgia's water use in the ACF Basin is not capped, I expect Georgia's consumptive use of water will continue to grow and cause even greater reductions in flow to the Apalachicola River. Based on further computer modeling I performed, I understand that absent a consumption cap, flows to the Apalachicola River could decrease by at least an additional 1,000 cfs in peak summer months of drought years. These reductions in flow are *in addition* to the present-day river flow reductions already being caused by Georgia's consumptive water use. Appendix B of my February 29 Expert Report presents these results. This additional use is likely to make extensive periods of low flow even more common for longer periods than the record-setting low flows of the past decade.

126. For this modeling of future growth, I used the water use estimates contained in Dr. Flewelling's Expert Report for the year 2050, and relied upon the research and analysis performed by Dr. Flewelling. In terms of future municipal and industrial water use, in 2015 Georgia updated its water supply request to the Corps asking to significantly increase water withdrawals from Lake Lanier to supply the Atlanta metropolitan area. The estimate of Georgia's municipal and industrial water use in 2050 that I used is based on Georgia's expected increase in water withdrawals for the Atlanta area. In terms of future agricultural water use, there are a multitude of reasons why we expect Georgia's agricultural water use to continue to increase significantly. As of 2014, Georgia has already permitted nearly 1,000,000 acres to be irrigated in the ACF Basin, which is over 300,000 more acres than Georgia's experts estimate for the present. If farmers begin irrigating on more of the acres already permitted or if Georgia

continues to permit more irrigated acreage, the impacts on flows to Florida will be even more severe.

X. IMPOSING A REMEDY THAT CAPS GEORGIA'S CONSUMPTION IS PRACTICAL AND VERIFIABLE

127. Capping Georgia's consumptive uses of water will provide tangible and practical benefits to streamflow in the Apalachicola River. In particular, the remedy Florida seeks in this matter consists of two components. I conclude that implementation of both components is practical and independently verifiable.

128. First, the Supreme Court could require Georgia to hold its annual average consumption to current levels through at least 2050. As described in the testimony of Dr. David Sunding, Georgia may select from a variety of relatively low-cost measures in Atlanta and elsewhere in the state to ensure its annual average consumption remains at current levels. As Dr. Sunding describes, these measures should not constrain metro Atlanta Georgia growth in a material way in the future.

129. Second, in severe drought years, the Supreme Court could require Georgia to make additional consumption cutbacks. In those years, the consumption cap would reduce depletions from the Flint and Chattahoochee Rivers by 1,500 to over 2,000 cfs in a peak drought summer month. As I describe below, the onset of drought can be reasonably anticipated using modern methods and relying on basic data sources. This capability facilitates implementation of drought conservation measures.

130. Both elements of this consumption cap remedy are practical and independently verifiable.

A. Existing Tools Reliably Indicate the Onset of Drought

131. There are a variety of pre-existing tools that reliably indicate the onset of drought and would enable Georgia to take appropriate action in advance of implementing conservation measures.

132. One such tool is the Standardized Precipitation Index (SPI) that indicates how far above or below average the precipitation for the previous 9 months is. I believe that SPI-9 is an appropriate tool for assessing the onset of drought in the Georgia portion of the ACF Basin. Negative SPI values correspond to lower rainfall, and larger negative values indicate drought. After reviewing the historical record of precipitation in the Georgia portion of the ACF Basin, I selected a value of -1.33 as the appropriate drought threshold. Any year in which the SPI-9 is lower than -1.33 signals the onset of a drought.

133. Once the drought trigger is exceeded, the conservation measures should remain in place until the system has recovered. The length of a drought event is typically taken to extend until the SPI-9 value returns to a positive value, not merely gone back above the threshold (https://www.ncdc.noaa.gov/paleo/drought/drght_spi.html). Return to a positive value can be considered recovery from drought.

B. Verification of Consumption Caps is Practical

134. The remedy Florida seeks in this case involves, among other things, holding water usage at current levels in the Metropolitan Atlanta area and implementing irrigation controls in the region where farming is located. I believe there are practical means to implement such a program.

135. Programs to hold urban water demands constant are feasible, based on accurate record-keeping, local steps to hold aggregate demands level, and third-party auditing of

withdrawals, returns, and aggregate usage. In my experience, such verification programs are routine and reliable.

136. Irrigation controls can be verified based on measurement, analysis and modeling. An effective program would include a surface water component and groundwater component.

137. Surface Water Component. Evaluating adherence with a consumption cap by measuring surface water is easily implemented. Using the existing USGS gage network above the Florida state line, potentially augmented with new gages at key locations would provide effective verification.

138. In addition, with agricultural reductions corresponding to about 1,000 cfs or more in the Georgia portion of the ACF, I have confidence that the streamflow benefits when measured on meaningful timescales will be detectable, and that meaningful progress against common measures of stream health can be assessed and will be seen.

139. Groundwater Component. The relationship between pumping, the Upper Floridan groundwater table, and base flow facilitates verifying that a conservation program is working as required. An important aspect of this verification program involves identifying a network of groundwater monitoring wells. Dr. Langseth explains that 20 existing groundwater monitoring wells serve as a reasonable cohort to assess the health of the Upper Floridan Aquifer. Data from these 20 wells, and perhaps others, may be used with known groundwater models to estimate base flow benefits in streams from reduced pumping. A third-party monitor with responsibility for verifying the levels in selected groundwater monitoring wells could ensure adherence to a remedy imposed in this case.

XI. GEORGIA’S ALTERNATIVE CAUSATION THEORIES ARE INCONSISTENT WITH THE BASIC DATA

A. The Data Show that Change in Climate Has Not Decreased Apalachicola River Flow

140. Based on my review of a number of climatological variables over the last century, as well as the work of Dr. Lettenmaier, there is no statistically significant trend in climate that can explain the observed decreases in low flows in the ACF Basin. Changes in climate cannot explain the losses in surface flows that have been observed in the Georgia potion of the ACF Basin.

141. Temperatures have not increased significantly within the ACF Basin over the last century. (See Lettenmaier Expert Report, FX-793.)

142. Similarly, there is no statistically significant trend in rainfall within the ACF Basin over the last century. Looking at monthly values from the Standardized Precipitation Index (SPI) to characterize drought and dry conditions over the last century using rainfall measurements, SPI values show no post-1970 trend that could explain the observed decreases in low flows (Hornberger Feb. 29 Expert Report, Figure 13). Recent droughts in the ACF Basin are not atypical for the region. The 1954 drought remains the most severe on record, and analysis of the paleoclimatic record, such as tree-ring data, shows that droughts as severe as recent examples within the ACF have been quite common over the past 350 years. (Pederson *et al.* 2012, FX-597.)

143. Likewise, potential evapotranspiration rates (a measure of the maximum ability of the atmosphere to remove water) within the ACF Basin have shifted only slightly over the last century. The Jaramillo and Destouni analysis indicates that, in the absence of evaporation from reservoirs and irrigated fields in the ACF, actual evapotranspiration would have decreased in the

ACF. This means that changes in temperatures and precipitation would actually have mitigated natural drought conditions rather than amplified them.

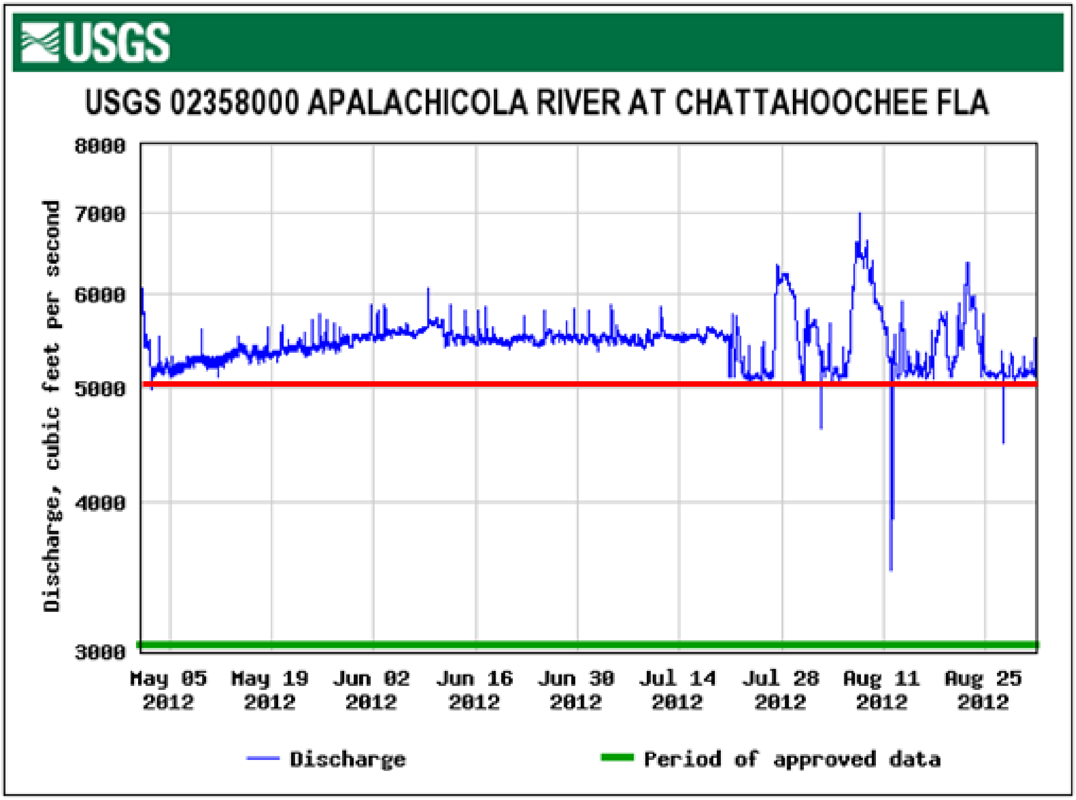
144. In any event, if, as Georgia apparently argues, climate changes exacerbate low flows during future dry periods, the need to constrain Georgia consumptive uses for agriculture and other uses would be more acute.

B. The Army Corps' Operations of the Reservoir System Are Not the Cause of the Decreased Apalachicola River Flow

145. Georgia contends that the Army Corps' operations are dictated by its ResSim model, and that the Corps releases the minimum amount of water dictated by the 2012 Revised Interim Operating Plan (RIOP). But declining flows cannot be explained by the Corps' operation of the federal reservoirs system along the Chattahoochee River. Dr. Shanahan explains in his testimony the limitations of the ResSim model and how Georgia has misinterpreted the RIOP. (See Shanahan Expert Reports.)

146. One example demonstrates the extent to which Georgia's theory conflicts with observed data. In the summer of 2012, USGS flow data from the Chattahoochee Gage station reveals that, as shown in Figure 11, during a period of Corps' drought operations, when the ResSim model would have predicted a consist flow of 5,000 cfs, the Corps released over 5,000 cfs nearly every single day, often by hundreds of cfs.

Figure 11. USGS Gage Data for Chattahoochee Gage, May Through August, 2012. This figure, which was prepared at my direction, shows a chart available on USGS's website (JX-128), during a period when the Corps was in drought operations. The only change made to this USGS figure was to add a red line at 5,000 cfs to show the flow that ResSim would predict during this period.



This is not to say that these flows were acceptable. Indeed, they were among the lowest flows in history and persisted for 8 months. But they were hundreds of cfs higher than ResSim would have predicted. This example illustrates why the Lake Seminole model was necessary. ResSim does not accurately predict actual flows.

C. Water Is Not Disappearing from the Apalachicola River within Florida, as Georgia Claims

147. Georgia claims that, since 1978, there have been large losses of water in the Apalachicola River between the Chattahoochee and Sumatra Gages in Florida, such that an

increasing volume of water equivalent to several thousand cfs of river flow[3] has essentially disappeared in recent decades in an area that has relatively little agriculture, minimal development, and a sparse population. Georgia bases this contention on a graph that it created showing the difference in uncorrected average annual discharge in the Apalachicola River between the Chattahoochee Gage, just downstream from Lake Seminole, and the Sumatra Gage, about 20 miles above the Bay. Georgia's assessment is fundamentally flawed in several ways.

148. Consumptive use in the Florida portion of the ACF Basin is much too small to explain the flow decline that Georgia alleges, and Georgia has not alleged any consumption to explain the purported decline. When the underlying gage data are corrected to account for gaging error and the fact that differences at low flows will be smaller than differences at higher flows (subtracting two small numbers results generally in a smaller number than subtracting two large numbers), no downward trend in flows is evident within Florida. (See Hornberger May 20, 2016 Expert Report, FX-804.)

149. Georgia fails to recognize the limitations of the Sumatra Gage. The Sumatra Gage is located on a portion of the river with a broad floodplain. During periods of high flow, water overflows the banks of the river's main channel, spreading across a wide area that is not readily measurable. Figure 12 shows how the river's pathways through the floodplain fan out during high-flow periods. Measuring flow under these circumstances is challenging and any failure to be consistent in measurement technique can lead to large errors, as has occurred here. The systematic error I found understates floodplain flow at Sumatra in more recent years, skewing a comparison between more recent times and times further back.

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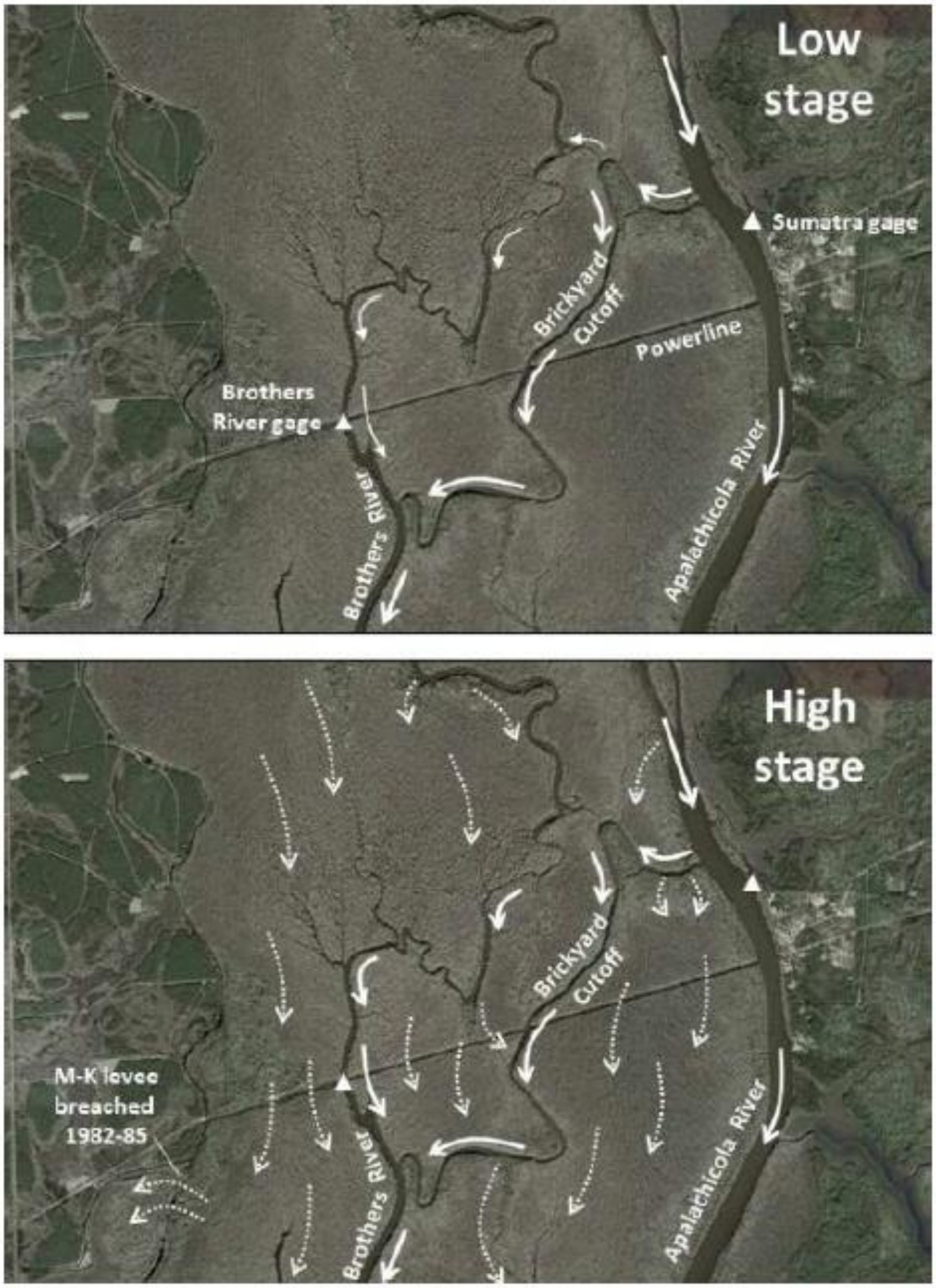
[3] At various times, Georgia's experts have contended that different quantities of water have gone missing, ranging from 2,640 cfs to over 10,000 cfs.

Figure 12. Flow Pathways in Stream Channels and Swamp Forests Across the River Floodplain near the Sumatra Gage. The low stage diagram depicts stage height of 3.9 feet or less, while the high stage diagram depicts stage height of 6.9 feet or higher. Solid arrows represent flows in permanently flowing channels; dashed arrows represent intermittently flowing floodplain sloughs or sheet flow through swamp forest. This figure was derived from flow and elevation data in Leitman *et al.* (1984) (FX-381), and topographic data from digital elevation models processed by the Northwest Florida Water Management District. This approach is based on generally accepted scientific principles and methods, which are commonly used by experts in my field.



150. The result of these physical and geographic properties of the region surrounding Sumatra is that gage data from the Sumatra Gage during high flow times are less reliable than data from a typical gage.

151. The USGS itself has acknowledged the serious flaws with the Sumatra Gage data during high flow times. In a letter dated July 25, 2016, the USGS stated that its "team did find a problem with several discharge rating changes made during 1990–2002 when erroneous discharge measurements were made during out-of-bank flood flows. Non-standard methods were used during several high flow measurements that under-reported the flows, which in turn led to inaccurate rating changes." (July 25, 2016 USGS Letter, FX-515 at 1.) I received and evaluated a copy of this letter, and FX-515 is a true and accurate copy of the letter I reviewed. As a hydrologist, I routinely rely on information from USGS, as do other experts in my field, and this letter supports my conclusion.

152. Finally, Georgia failed to account for the fact that the magnitude of the differences between a downstream and an upstream gage is related to the amount of flow in the river. Flow differences between two points are a function of the flow itself, with flow differences in general being larger at high flows and lower at low flows. This dependence must be taken into account in order to properly analyze any trends in flow differences between two gages.

153. In order to come as close as possible to correctly reflecting actual flow levels at Sumatra over time, so as to make a fair comparison over time, I created corrected gage data for Sumatra. I accomplished this by taking the rating curve for Sumatra from Water Years 1978 to 1985 (prior to the methodological changes in measurement implemented by the USGS), using

this curve as a stable relationship for the entire period of record, and calculating an adjusted discharge hydrograph for the full period.

154. My adjusted discharges are much higher than the reported values in recent years, in essence accounting for the apparent drop in measured flow. There is no loss of water over time. Both the apparent massive loss of water between the Chattahoochee Gage and Sumatra Gage and the apparent increase in this trend over time are entirely spurious.

XII. CONCLUSION

155. Georgia's dramatic increase in consumptive use over the last several decades has caused a tremendous impact on streamflow in the Apalachicola River. Several reliable and well-established hydrological tools and methods demonstrate this relationship. These tools and methods also demonstrate that imposition of a particular consumption cap will result in tangible benefits to Florida in the form of increased streamflow in the Apalachicola River.