LANGSETH PRE-FILED DIRECT
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 DR. DAVID E. LANGSETH, Sc.D, P.E., D. WRE

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I. INTRODUCTION

1. I am a registered professional engineer with more than 30 years of domestic and international experience in both consulting and academic settings. My areas of expertise include surface and groundwater hydrology and hydraulics (including the interaction of surface and groundwater flows), as well as surface and groundwater quality, contamination, and pollution-containment issues.

2. To analyze groundwater pumping in the Apalachicola-Chattahoochee-Flint (ACF) River Basin, I used a variety of approaches that are generally accepted in my field, including performing simple calculations based on basic hydrologic data and using results from hydrologic models. (*See, e.g.*, Expert Report of Dr. David Langseth (February 29, 2016) ("Langseth Report"), FX-795.) Based on my analysis, I have formed the following opinions:

   a. The Upper Floridan Aquifer is a naturally occurring underground reservoir. There is a strong hydrologic connection between the Upper Floridan Aquifer and substantial portions of the Flint and Chattahoochee River Basins. (Langseth Report at SS-5, 41.) The hydrologic connection enables streams to receive "baseflow" from the aquifer, where "baseflow" means groundwater that discharges from aquifers to streams and rivers. (*Id*. at 7.)

   b. When Georgia pumps groundwater from the Upper Floridan Aquifer, it reduces the baseflow that supplies streams and rivers during dry periods and therefore reduces streamflow in the Flint and Chattahoochee River Basins. (*Id*. at 31.) Because the Apalachicola River receives streamflow from the Flint and Chattahoochee River Basins, streamflow reductions in the Flint and Chattahoochee River Basins reduce streamflow in the Apalachicola River and to the Apalachicola Bay. (*Id*. at SS-5.) I call the amount by which streamflow is reduced "streamflow depletion."

c. Since the advent of large-scale agricultural irrigation in Georgia, and the intense pumping associated with that irrigation, groundwater levels in the Upper Floridan Aquifer have declined. (*Id*. at SS-6.) In recent decades, these declines have accelerated, resulting in an average decline of approximately 4.7 feet since 1992. (*See* Langseth Report, Appendix C; Panday Dep. Tr. (August 1-3, 2016), Exs. 58-62, FX-548–FX-552.) Analysis of the 20 groundwater monitoring wells that Georgia's expert, Dr. Panday, also evaluated indicates that groundwater levels in Georgia portion of the ACF Basin have declined, on average, by 4.7 feet since 1992. (*See* Panday Dep. Tr. (August 2, 2016), Ex. 62, 560:05–568:11, FX-552.) This groundwater decline indicates that the Upper Floridan Aquifer has been pumped at rates it cannot sustain. (*Id*. at SS-6.)

d. Dr. Panday's analysis confirms my opinion that reduced groundwater levels reduce baseflow and thereby add to the streamflow depletions caused by pumping. (Langseth Report at SS-6, 31-33) I believe, however, that Dr. Panday employed a flawed methodology for calculating streamflow depletions caused by reduced groundwater levels, and that if he had used generally accepted hydrologic methods for direct evaluation of baseflow (*e.g.*, the USGS "PART" method) and groundwater levels, he would have calculated higher streamflow depletions for every foot of groundwater decline (*e.g.*, 340 cfs depletions for every 1-foot decline in groundwater elevation levels).

e. My analysis indicates that fundamental hydrological characteristics in the Georgia portion of the ACF Basin have changed since the widespread implementation of intensive agricultural pumping in Georgia. (Langseth Report at SS-5.) Among other things, these fundamental changes are evidenced by (i) the high number of days since 1980 when Spring Creek has run dry (before 1980 this did not occur) (*id*. at SS-5, 43,

Appendix D, D-15); (ii) the fact that a given amount of precipitation and recharge produces less baseflow from the Upper Floridan Aquifer in Georgia than it used to (*e.g.*, *id*. at 43 (citing Rugel *et al.*, 2009; Rugel *et al.*, 2012; Hicks and Golladay, 2009; Golladay and Hicks, 2013); and (iii) observations of groundwater flows reversing direction during drought, causing normally gaining streams to become losing streams. (*Id*. at SS-5, 19, 41-42.) In my opinion, Georgia pumping is the primary cause of these fundamental hydrologic changes. (*Id*. at SS-5-6.) This opinion is consistent with Dr. Hornberger's analyses and conclusions concerning Georgia's consumptive water use.

f. My analysis shows that for every 1.0 gallon of water pumped from the Upper Floridan Aquifer there is a *long-term* (potentially years) *loss* of streamflow of about 0.9 gallons. (Langseth Pumped Water Source Notes, FX-585 at 1; Langseth Dep. Tr. 1023:21–1024:13 (August 16, 2016).) Over the short term, for every 1.0 gallon of groundwater pumped from the Upper Floridan Aquifer, there is a *short-term loss* of streamflow ranging from about 0.4 gallons (a conservative, lower bound) to about 0.6 gallons (a more likely value). (Langseth Dep. Tr. 1161:11-15 (August 18, 2016); Langseth Report, Appendix D at D-5.)

g. The most severe streamflow impacts occur during multiple-year droughts when streamflow depletions caused by high drought-year irrigation (pumping impacts) combine with the impacts from already reduced groundwater levels (baseflow impacts)—levels that have not recovered between growing seasons and thus begin in a deficit position. (Langseth Report at SS-6, 32-33, 48-49.)

h. Georgia pumping from other aquifers in the ACF Basin—*i.e.*, the Claiborne, Clayton, and Providence/Cretaceous aquifers—also reduces baseflow and causes streamflow depletions. (Langseth Report at SS-5, 19.) Pumping from the Upper Floridan Aquifer, however, produces the largest short-term streamflow depletions, both in terms of total depletions and the ratio of pumping to depletions ("impact factor"). (*Id*.)

i. I reviewed the report that Georgia's expert Dr. Sorab Panday produced on May 20, 2016 ("Panday Report"). In his report, Dr. Panday claimed that vast quantities of water are vanishing in the "Incremental Area"—*i.e.*, the largely undeveloped area of the Florida portion of the ACF Basin between the Chattahoochee and Sumatra gages. (*See* Panday Report at 25-26, C-5.) According to Dr. Panday, real water losses have ranged from about 3,000 cfs to nearly 10,000 cfs, but he did not postulate an explanation or cause of these purported losses. I believe Dr. Panday's opinions on 'lost water' are based on fundamentally flawed methodologies; my analysis establishes that the phenomenon Dr. Panday describes is not occurring. (Langseth, Panday Water Budget Evaluations, June 28, 2016, FX-805.)

II. PROFESSIONAL BACKGROUND

3. I hold a Bachelor of Arts degree in Mathematics and a Bachelor of Civil Engineering (with high distinction) from the University of Minnesota (1977). I received a Master of Science degree (1980) and a Doctor of Science degree (1983), both in Civil Engineering, from the Massachusetts Institute of Technology (MIT).

4. From 2000 through 2004, I served as an Associate Professor in Civil and Environmental Engineering at Northeastern University, where I taught courses in groundwater and surface water hydrology, among other topics. From 2010 through 2015, I held an appointment as a Senior Lecturer and Research Associate in the Department of Civil and Environmental Engineering at MIT, concurrent with my employment at Gradient. My academic research focused on groundwater/surface water interactions, groundwater hydraulics, risk

management for hydrologic structures, and water-quality management. My work has been published in a number of peer-reviewed journals, including *Ground Water*, *Journal of Water Resources Planning and Management*, and *Journal of Geologic Education*.

5. Since 2004, I have worked as a Principal at Gradient, an environmental and risk-sciences consulting firm based in Cambridge, Massachusetts. Earlier in my career, I worked at two other engineering and scientific-consulting firms: Exponent, Inc., from 1996 to 2000, where I served as a Principal Engineer and Regional Manager, and Arthur D. Little, Inc., from 1984 through 1996, where I was Vice President and Director.

6. I am a member of the American Society of Civil Engineers and the National Ground Water Association, for which I serve as representative to the Advisory Committee on Water Information ("ACWI"), a federal group charged with improving water information for decision making about natural-resources management and environmental protection. Since 2007 I have been a member of the ACWI Subcommittee on Groundwater, charged with developing a national groundwater-monitoring network.

7. My curriculum vitae, included in my expert report, provides further information regarding my professional background. (Langseth Report, Appendix A.)

III. KEY TERMS

8. In this section, I describe some important hydrologic terms that I refer to in my testimony.

9. **ACF Basin**: The area within which water drains to the Apalachicola, Chattahoochee, or Flint Rivers.

10. **Aquifer**: A subsurface formation that yields useable quantities of water to pumping

11. **Baseflow**: The flow in a stream that is provided by groundwater discharging to the stream. The remainder of the flow is provided by surface or near-surface runoff during or shortly after precipitation occurs.

12. **Hydrologic connection**: Two water bodies (such as an aquifer and a stream) are hydrologically connected if, under natural conditions, water flows between them. A hydrologic connection may be characterized as "strong" or "weak" depending on the degree to which water moves between the two water bodies.

13. **Impact factor**: The ratio between the pumping rate and the streamflow depletion rate. Impact factors may be defined for various time periods, generally months or years.

14. **Karst**: The Upper Floridan is a karst aquifer, consisting generally of carbonate rocks (such as limestones), and characterized by the presence of open spaces in rock that has been eroded by dissolution in water. The open spaces can vary in size from a fraction of an inch to sinkholes tens of feet in diameter, or more, to caverns.

15. **Productive aquifer**: An aquifer that yields relatively large quantities of water to pumping as compared to other aquifers.

16. **Recharge**: Precipitation that enters an aquifer.

17. **Seasonal factor**: The ratio between the streamflow depletion during the peak month or season and the annual-average depletion.

18. **Streamflow**: Total flow rate of water in a stream or river.

IV. RELEVANT BACKGROUND

19. In this section of my testimony, I describe the geological and hydrogeological setting of the ACF Basin, focusing on the interactions between surface water and groundwater.

20. In the Coastal Plain, where most groundwater pumping in the ACF Basin occurs, there are 4 principal aquifers: Upper Floridan, Claiborne, Clayton, and Providence/Cretaceous.

(Langseth Report at SS-5, 19.) The Upper Floridan Aquifer is by far the most productive of these four principal aquifers. It also is the most intensely exploited for irrigation pumping in Georgia. (*Id*.)

A. There is a strong hydrologic connection between groundwater in the Upper Floridan Aquifer and streamflow in the Lower Flint River and the downstream reaches of the Chattahoochee River.

21. There is a strong hydrologic connection between groundwater in the Upper Floridan Aquifer and streamflow in the Lower Flint River Basin and the downstream reaches of the Chattahoochee River Basin. The physical reason for this is related to the geology of the system. (Langseth Report at SS-5.)

22. The Upper Floridan Aquifer is composed of several limestone and sand formations. Much of the limestone within the Upper Floridan Aquifer consists of rock containing karst features, some quite large, such as the blue-hole springs. (*Id*. at 52) The karst features of the Upper Floridan Aquifer facilitate the movement of groundwater; for example, the springs act as conduits to discharge groundwater to the streams in the form of baseflow. Similarly, water can flow easily through the many sinkholes. These karst features are largely responsible for the highly productive nature of the Upper Floridan Aquifer, as well as the strong hydrologic connections that exist between the Upper Floridan Aquifer and the Lower Flint River and lower reaches of the Chattahoochee River. Figure 1 shows an example of karstic rock.

Figure 1. Groundwater emerging at the surface in karstic rock in Florida. (*See* https://www.flmines.com/phpLD/LEISURE/Outdoor/florida%E2%80%99s-karst-aquifers-and-springs-are-natural-ground-water-movement-systems-437.html.)

23. The major streams in the Lower Flint River and Chattahoochee River Basins, and some of the larger tributaries, are "incised" into the Upper Floridan Aquifer. (Langseth Report at SS-1.) By this I mean that the stream channels cut directly into the limestone rock of the Upper Floridan Aquifer, as depicted in Figure 2. The object labeled "solution feature" identifies a zone where the limestone has dissolved, a karstic feature. Water can flow through such open zones more easily than through areas dominated by solid limestone, in which water must flow through a network of tiny pores.

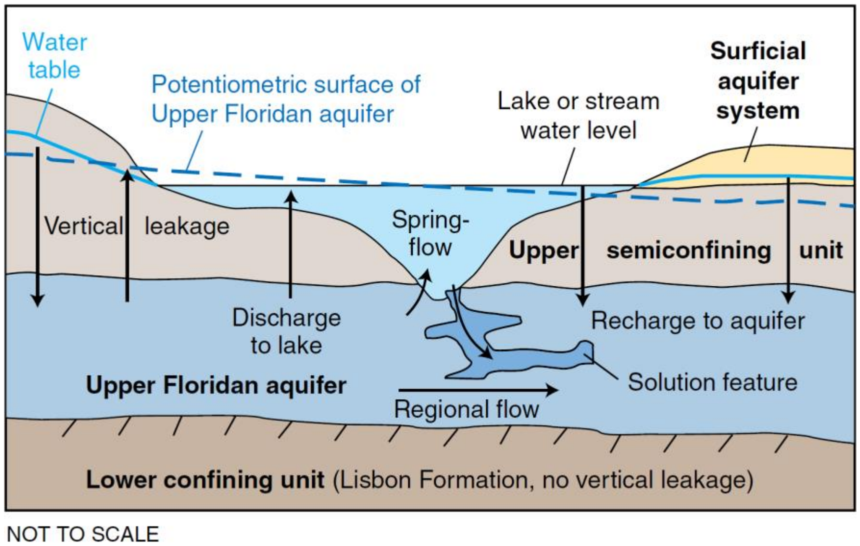


Figure 2. Conceptual Framework of the Connection Between Groundwater and Surface Water. (Langseth Report, FX-795 at SS-3, 38 (citing Torak & Painter, 2006, GX-90 at 16).)

B. During dry periods, baseflow from the Upper Floridan Aquifer provides most of the water to the Lower Flint River.

24. When there is sufficient groundwater to discharge baseflow to streams, those streams do not run dry, even when it has not rained for weeks or longer. (Langseth Report at 7.) During dry periods, most of the flow in the Flint River is baseflow. (Id. at 31.) Most of this critical baseflow originates from groundwater in the Upper Floridan Aquifer (*id.*), though the other Coastal Plain aquifers collectively contribute substantial baseflow as well. (*Id*. at SS-5, 19.) The same is generally true for the lower Chattahoochee River, though the relative contributions of the various aquifers may be different than for the Flint River Basin.

25. A stream or stream segment that *gains* water from groundwater is called a “gaining stream” or “gaining reach.” (*Id*. at 9.) Whether a stream or stream segment is “gaining” or “losing” depends on the relationship of the groundwater level to the streambed. (*Id*.) A stream or stream segment that loses water to groundwater, through seepage of surface water flows to underlying aquifers, is called a “losing stream” or “losing reach.” (*Id*.) If a stream or stream segment is to gain water from groundwater, the groundwater elevation must

exceed the water level in the stream, thereby enabling the groundwater to discharge into the surface water. (*Id.*) Under natural conditions—*e.g.*, absent groundwater pumping in Georgia—streams and stream segments in the Georgia portion of the Flint River Basin gain water from underlying aquifers, including the Upper Floridan Aquifer. (*Id*. at 41.)

26. Baseflow from the Upper Floridan Aquifer plays a critical role in supporting streamflow in the Flint River—and ultimately the Apalachicola River too. That role is analogous to the role that Lake Lanier plays for Georgia's water supply. Lake Lanier is a highly visible resource to Georgia; it sustains metropolitan Atlanta water supplies, even during dry periods when it is not raining. The Upper Floridan Aquifer is similarly essential to Florida: its groundwater provides baseflow that ultimately reaches the Apalachicola River, thereby sustaining flow even during dry periods when there is little or no rain. (*Id*. at SS-6.)

27. A hydrologic connection also exists between the Claiborne aquifer and streamflow in the ACF Basin, but that connection is weaker than between the Upper Floridan Aquifer and streamflow in the ACF Basin. (Langseth Report at SS-5, 19.) The Clayton and Providence/Cretaceous aquifers are also hydrologically connected to surface waters in the ACF Basin, but the connections are weaker than those in both the Upper Floridan and Claiborne aquifers. (*Id*.) Nonetheless, these three aquifers collectively do provide substantial baseflow to the Flint and Chattahoochee Rivers.

C. Groundwater pumping decreases groundwater storage and baseflow.

28. When a well pumps water from the ground, the groundwater level at the well declines, thereby causing nearby groundwater to flow toward the well. (Id. at 41-42.) Groundwater-level declines from pumping also reduce the slope or "gradient" at which groundwater would otherwise flow towards and discharge into streams as baseflow. (*Id*. at 19.)

When the gradient declines, so does the rate at which baseflow discharges to the streams, causing reduced flow rates during dry periods. (*Id*.)

29. If well pumping is sufficiently intense, it can reverse the natural flow direction of groundwater, causing water already in a stream to flow back into the aquifer, creating a losing stream. (*Id*. at 9.) In extreme situations, groundwater elevation levels can fall below streambed elevations, and if there also is no rain, streams can run dry. (*Id*. at 31-33.)

30. If the lowered groundwater levels caused by pumping are not restored by additional recharge (*i.e.*, precipitation that infiltrates into the aquifer), the streamflow depletions will continue. (*Id*.) Additionally, when the lowered groundwater levels are restored, the water used to restore those levels does not flow to the stream, causing additional streamflow depletions. (*Id*.)

31. The Upper Floridan Aquifer system is one of the most well-studied and prolific aquifers in the United States. (*Id*. at B-6.) Its physical features and hydrological conditions have been well defined and documented through years of investigations. (*Id*.)

32. What I have described above are generally agreed upon hydrologic principles. Other hydrologists that have studied the ACF Basin agree that there is a strong connection between groundwater levels in the Upper Floridan Aquifer and streamflow, and that pumping for irrigation reduces groundwater levels and streamflow. (*Id*. at 19 (citing Reheis, 1999, FX-2, Reheis Exhibit 4, Deposition of Reheis, Jan. 27, 2016, 23:23–24:21), 20 (citing Pierce *et al.*, 1984), 37-38 (citing to Jones & Torak, 2006; Crandall *et al.*, 2013; Camp Dresser & McKee, 2011), 41.) In other words, it is beyond dispute that groundwater pumping in the Georgia portion of the ACF Basin impacts streamflow in the ACF Basin. To the extent hydrologists

disagree about the impacts of pumping on streamflow, those differences concern the degree and timing of these impacts—not their existence.

V. GEORGIA PUMPING IS IMPACTING THE UPPER FLORIDAN AQUIFER AND REDUCING ITS ABILITY TO PROVIDE BASEFLOW TO THE APALACHICOLA RIVER, ESPECIALLY DURING DRY SUMMER MONTHS

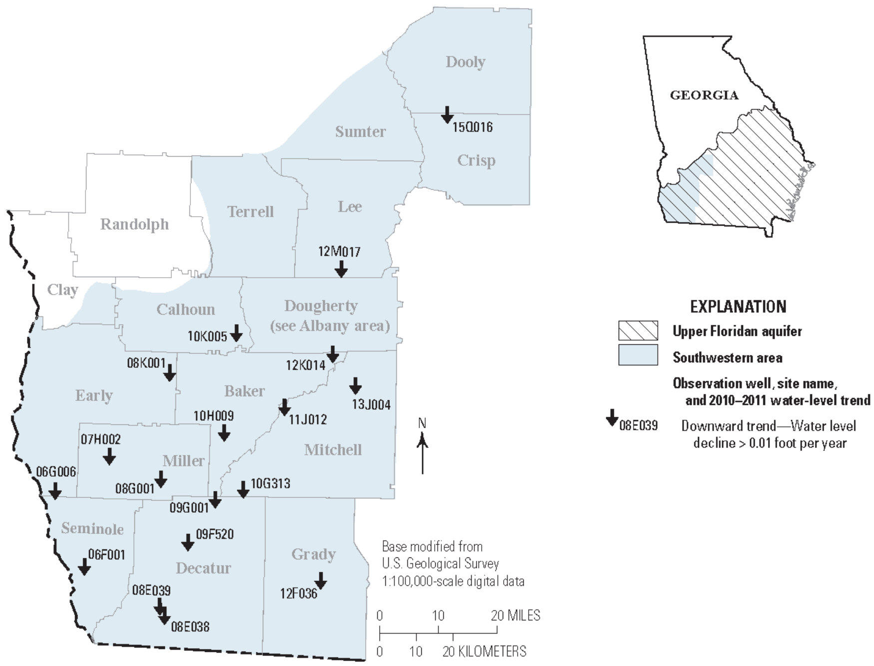
33. The hydrologic analyses that I have conducted demonstrate that groundwater pumping from the Upper Floridian Aquifer in the Lower Flint River Basin is causing substantial streamflow depletions. Analyses by or on behalf of Georgia support this conclusion.

A. Since 1992, groundwater levels in the Upper Floridan Aquifer have trended downward, substantially reducing baseflow.

34. An aquifer's groundwater levels are a common measure of its condition and whether it has been impacted. (Langseth Report at SS-6, 36.) In the absence of climate change, long-term declines in groundwater levels provide evidence of unsustainable pumping practices. (*Id*. at SS-6.)

35. My expert report explains that groundwater levels in the Upper Floridan Aquifer are generally declining, at long-term rates of up to about 1 ft/yr in some locations, but at rates up to 17 ft/yr during the 2010-2011 drought. (*Id*. at 31.) To support this opinion, I analyzed USGS groundwater well monitoring data, in addition to a number of studies on groundwater levels in the Upper Floridan Aquifer. (*Id.*) Peck *et al.* (2013) (JX-83) present an overview of groundwater conditions in Georgia based on data from 17 wells in the Georgia portion of the ACF Basin with monitoring records beginning as early as 1972. (Langseth Dep. Tr. (June 17, 2016), Ex. 18.) See Figure 3 below.

Groundwater Conditions 21



Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2010 to 2011
10H009	Baker	1998	0.10	–11.14
12K014	Baker	1982	–0.09	–7.06
10K005	Calhoun	1983	–0.11	–4.17
15Q016	Crisp	2002	–1.12	–15.71
08E038	Decatur	2001	0.05	–1.19
08E039	Decatur	2002	–0.06	–1.16
09F520	Decatur	1972	–0.06	–5.27
09G001	Decatur	1980	–0.07	–6.11
06G006	Early	1982	–0.08	–12.76
08K001	Early	1982	–0.04	–17.77
12F036	Grady	1971	0.24	–3.88
12M017	Lee	1982	–0.01	–8.65
07H002	Miller	1980	0.30	–6.21
08G001	Miller	1977	–0.15	–13.78
10G313	Mitchell	1976	–0.09	–9.42
11J012	Mitchell	1981	–0.06	–5.62
13J004	Mitchell	1978	–0.22	–8.12
06F001	Seminole	1979	–0.13	–10.82

[1]See appendix for summary statistics.

Figure 3. Peck *et al.* (2013) JX-83 at 21. The table provides water-level trend records from 18 groundwater monitoring stations, but the Grady County station is not located in the Georgia portion of the ACF Basin.

36. Of the 17 Georgia groundwater monitoring wells identified in Figure 3, USGS reported that 15 experienced declining water-level trends of up to 1.12 feet per year ("ft/yr"). (Peck *et al.* (2013) JX-83 at 21.) During the 2010-2011 drought period, USGS reported groundwater declines of up to 17.77 ft/yr. (*Id*.)

37. In his expert report, Dr. Panday evaluated groundwater data collected from 1975-2015 from a series of 20 wells in the Georgia portion of the ACF Basin. (Panday Report at 23-4 (Section 5.2.1), 28-29 (Section 6.1.2), Appendix C at C-11-13 (Section C.4.2), Figure C-24, Table C-2.) *See, e.g.*, Figure 4 (from Dr. Panday's Report). These wells were included among the 140 USGS groundwater wells whose monthly data I analyzed in my expert report. (Langseth Report, Appendix C, C-1 and Table C.2.) Based on his evaluation, Dr. Panday concluded that "groundwater levels in the UFA . . . are generally stable . . . [and] there is no evidence of a systematic basinwide impact to long-term aquifer levels caused by groundwater pumping." (Panday Report at 23.)

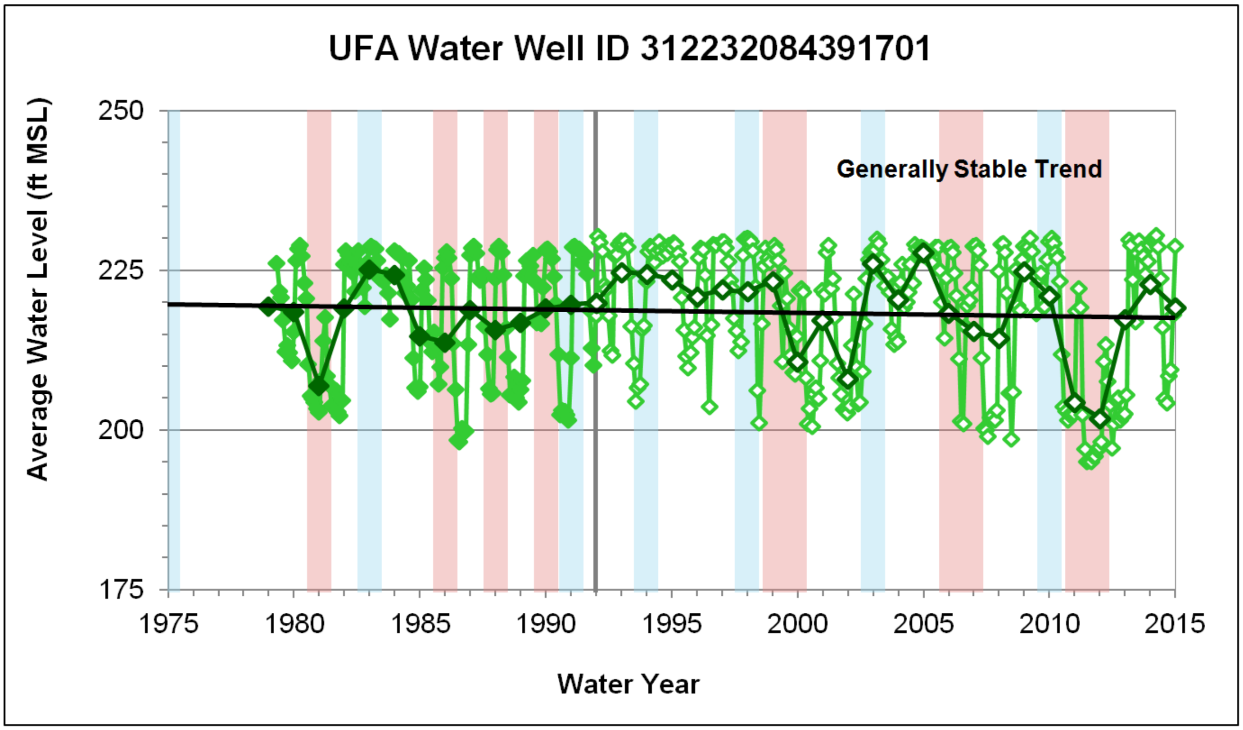


Figure 4. Dr. Panday's Analysis of UFA Water Well ID 312232084391701 (Panday Report at Figure C-24 (regression line fit through the 1975-2015 time period).)

38. I analyzed data from the 20 wells Dr. Panday selected, focusing on the two time periods for which he provided "summary statistics" in his report—*i.e.*, pre- and post-1992. (Panday Report at Appendix C, Figure C-24). I specifically evaluated whether any groundwater-level trends could be discerned during the pre- and post-1992 time periods.

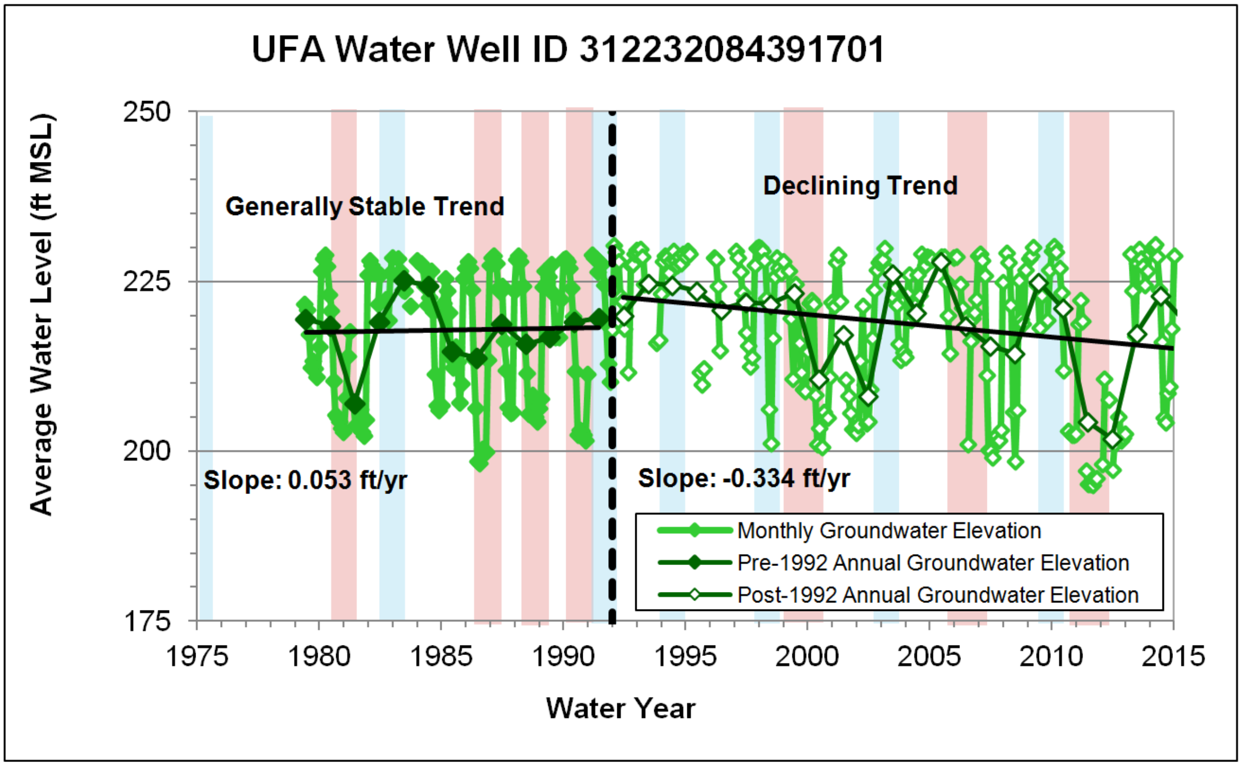


Figure 5. Gradient Analysis of UFA Water Well ID 312232084391701 (Panday Dep. Tr. (August 2, 2016), Ex. 60, 548:15–550:25, FX-550 (at my direction regression lines were fit through the pre- and post-1992 time periods indicating a steep decline in groundwater levels at this particular well since 1992).)

39. These results were presented to Dr. Panday during his August 1-3 deposition. (*See* Panday Dep. Tr. (August 2, 2016), Exs. 58-62, FX-548–FX-552.) They establish that since 1992, groundwater levels at *only two* of the wells that Dr. Panday studied remained "generally stable"; groundwater levels at all of the other 18 wells experienced declines. (*See* Panday Dep. Tr. (August 2, 2016), Exs. 58, 62, FX-548, FX-552.)

Pre- and Post-1992 Trend Analysis of UFA Water Wells Reviewed by Dr. Panday (Table C-2, Figure C-24)

UFA Water Well ID	Site Name	Panday Analysis		Gradient Analysis			
		Period of Record		Pre-1992		Post-1992	
		Slope[a] (ft/yr)	Linear Trend[b]	Slope (ft/yr)[c]	Linear Trend[d]	Slope (ft/yr)[c]	Linear Trend[d]
311009084495502	07H002	0.22	Increasing	0.19	Increasing	-0.10	Generally Stable
305356084534601	06F001	-0.07	Generally Stable	0.10	Generally Stable	-0.15	Declining
312232084391701	08K001	-0.04	Generally Stable	0.05	Generally Stable	-0.33	Declining
310651084404501	08G001	-0.11	Declining	0.06	Generally Stable	-0.31	Declining
313808084093601	12M017	-0.01	Generally Stable	-0.17	Declining	-0.12	Declining
312853084275101	10K005	-0.07	Generally Stable	0.00	Generally Stable	-0.12	Declining
314330084005402	13M006	-0.07	Generally Stable	0.30	Increasing	-0.19	Declining
313521084051001	13L049	-0.11	Declining	0.62	Increasing	-0.23	Declining
313450084091801	12L029	0.07	Generally Stable	0.04	Generally Stable	-0.16	Declining
313105084064302	13L012	-0.04	Generally Stable	0.07	Generally Stable	-0.15	Declining
313031084005901	13L048	-0.40	Declining	-0.70	Declining	-1.19	Declining
313130084101001	12L030	-0.07	Generally Stable	0.25	Increasing	-0.19	Declining
312919084153801	11K003	-0.11	Declining	-0.24	Declining	-0.19	Declining
312704084071601	13K014	-0.07	Generally Stable	-0.24	Declining	-0.14	Declining
312617084110701	12K014	-0.07	Generally Stable	-0.06	Generally Stable	-0.14	Declining
312127084065801	13J004	-0.26	Declining	-0.19	Declining	-0.50	Declining
311802084192302	11J012	-0.04	Generally Stable	0.01	Generally Stable	-0.11	Declining
310507084262201	10G313	-0.11	Declining	-0.01	Generally Stable	-0.20	Declining
310428084310501	09G001	-0.07	Generally Stable	-0.06	Generally Stable	-0.14	Declining
305736084355801	09F520	-0.07	Generally Stable	-0.06	Generally Stable	-0.10	Generally Stable

Notes:

(a) Slope values reported in Table C-2 of Dr. Panday's expert report (May 20, 2016) and were calculated from trend lines fit through each well's entire period of record between 1975-2015 (Figure C-24).

(b) Dr. Panday used the following criteria to characterize linear trends, "Declining" = decreasing slope ≤ -0.11 ft/yr; "Generally Stable" = -0.11 < Δslope < 0.11 ft/yr; and "Increasing" = increasing slope ≥ 0.11 ft/yr (Panday Expert Report, Table C-2, footnote 3).

(c) Pre- and Post-1992 slope values were estimated by fitting a least squares linear regression trend line to annual average groundwater elevation data, implemented in Excel using the "Add Trendline" function. The post-1992 linear trend analyses included the years 1992 and later for each well.

(d) Linear trends were characterized based on Dr. Panday's criteria described in (b) above.

Figure 6. (Panday Dep. Tr. (August 2, 2016), Ex. 61, 555:14–560:04, FX-551.)

40. My analysis of the data from Dr. Panday's 20 wells indicates that, on average, groundwater levels have ***dropped about 4.7 feet since 1992***. (*See* Panday Dep. Tr. (August 2, 2016), Ex. 62, 560:05–568:11, FX-552). By contrast, during the pre-1992 time period, three of the wells were "Increasing," eleven were "Generally Stable," and only five were "Declining." This evidence indicates that intensive irrigation practices in the Georgia portion of the ACF Basin, particularly in the Flint River Basin, have contributed to long-term declines in Upper Floridan Aquifer groundwater levels since the 1990s, reinforcing the opinions in my report (Langseth Report at SS-6.)

41. According to fundamental hydrologic principles, baseflow generally declines when groundwater levels decline. (FX-82.) Dr. Panday's modeling demonstrates this fundamental principle. (Panday Report, Appendix F at F-4.)

42. Dr. Panday's analysis indicates that a decline in the Upper Floridan Aquifer of 2 feet in 20 years would reduce streamflow by ***40% of the pumping-related streamflow depletions*** he calculated. *Compare* Panday Report at 26 (concluding that maximum pumping under a dry scenario (July 2011) would reduce baseflow by 538 cfs) with Panday Report at 29 (concluding that a 2-foot decline in groundwater levels over 20 years would reduce baseflow by up to an additional 217.5 cfs, where 217.5/538 = 0.4 or 40%.)

43. Dr. Panday's approach for quantifying baseflow reductions due to reduced groundwater levels is flawed in at least two respects. First, his baseflow-reduction calculations derive from his manipulation of parameters in the Jones and Torak model—an artificial simulation exercise that does not reflect real-world conditions of rising and falling groundwater levels. Second, Dr. Panday's application of the Jones and Torak model produced counterintuitive and erroneous baseflow results, calling into question its ability to reliably predict actual baseflow values. Under Dr. Panday's drought scenario simulations, baseflow values were *higher* than under the normal scenario that he modeled. In other words, Dr. Panday's model predicted that in a severe drought year (2011), the Upper Floridan Aquifer would discharge *more baseflow* to surface water than in a normal year (2001) (Panday Tr. (August 1, 2016) at 293:19–297:7 (discussing Ex. 34))—a result that Dr. Panday recognized defies common sense. (Panday Tr. (August 1, 2016) at 78:6-15; *id*. at 114:13–115:4.)

44. Had Dr. Panday directly evaluated how baseflow changes with groundwater level changes, by using groundwater-level data and baseflow estimation methods such as the USGS

"PART" method—a standard baseflow-calculation method included in the USGS Groundwater Toolkit, which Dr. James Kennedy, Georgia State Geologist, employed to calculate Flint River Baseflow (Panday Dep. Tr. (August 1, 2016), 144:12–146:12 (discussing Ex. 13))—Dr. Panday would have calculated a significantly higher baseflow reduction (*e.g.*, on the order of 340 cfs for every foot of groundwater decline, or over 1,000 cfs for every 4-ft decline in groundwater levels.)

45. In any given growing season, pumping reduces baseflow in the short term. This short-term reduction, however, adds to the impacts of prior pumping and weather conditions that may have already reduced groundwater levels at the beginning of that growing season. As I discuss above, groundwater levels in the Upper Floridan Aquifer are trending downward, and reduced groundwater elevations reduce total baseflow. Thus, as Dr. Panday found, during those years when groundwater levels fall below baseline levels (*e.g.*, 1992), those declines produce additional streamflow depletions, adding to the short-term streamflow depletions attributable to pumping.

46. My groundwater-level trend analysis shows that average groundwater levels are declining in the Upper Floridan Aquifer. Lower groundwater levels lead to lower baseflow rates. My analysis on this point is consistent with and supportive of Dr. Hornberger's opinion that streamflow yields in the ACF basin have declined since intense agricultural pumping began in Georgia. (*E.g.*, Expert Report of Dr. George Hornberger (February 29, 2016) ("Hornberger Report") at 15 .)

B. The fundamental hydrologic characteristics of the ACF Basin have changed: for given rates of precipitation and recharge, the Upper Floridan Aquifer in Georgia yields less baseflow than it did before the widespread implementation of intensive agricultural pumping.

47. Since the advent of large-scale agricultural pumping, low flows in the ACF Basin are more common and more severe than they were previously. (Hornberger Report at 22-25; *see also* Langseth Report at 43 (citing Rugel *et al.*, 2009; Rugel *et al.*, 2012; Hicks and Golladay, 2009; Golladay and Hicks, 2013).)

48. My analysis indicates that the fundamental hydrologic characteristics of the ACF Basin have changed. (Langseth Report at SS-5.) These fundamental changes in the natural hydrologic relationship between groundwater and surface water are clearly illustrated by the numerous days on which Spring Creek has run dry since 1980, compared to never having run dry prior to 1980. (*Id*. at SS-5, 43, Appendix D, D-15.)

49. Additionally, streams and springs in the Lower Flint River Basin that have historically been gaining have become losing or dry. (*Id*. at SS-5, 19, 41-42.) The flow of groundwater has reversed direction, causing streams in the Lower Flint River Basin to inundate springs naturally filled by Upper Floridan Aquifer groundwater, turning "blue-hole" springs brown and muddy. (*Id*. at SS-5, 19, 41-42; *see* Gordon *et al.* 2012, JX-54 at 16.) Normally gaining streams become losing or dry streams during drought at least in part because of pumping (Langseth Report, FX-795 at SS-5.) *See* Figure 7.

Figure 7. Blue-Hole Spring in the ACF Basin During Normal Conditions (2003) (see top photo "A") and Drought Conditions (2011) (see bottom 3 photos ("B"). Source: Gordon *et al.* 2012, Figure 10, JX-54.

50. The reduced baseflow yield in the Upper Floridan Aquifer, as compared to years prior to the widespread implementation of intense agricultural pumping, also reflects these fundamental hydrologic changes. (Panday Tr. (August 1, 2016), Ex. 13 (October 31, 2011 Memorandum by Dr. James L. Kennedy, Georgia Geologist) (*see* FX-231).)

51. Dr. Kennedy calculated chronically low baseflow during recent drought periods. (*Id*.) These baseflow declines, as compared to baseflow during severe droughts prior to the advent of large-scale intense irrigation pumping, indicate the strong impact of that pumping on baseflow, particularly during drought periods. (Langseth Report at 23.)

52. These fundamental changes are not due to climate change. As shown by Drs. Hornberger and Lettenmaier, nature continues to supply water to the ACF Basin and the Upper Floridan Aquifer as it always has; precipitation has remained stable. (Expert Report of Dr. George Hornberger, February 29, 2016, FX-785 at 27; Expert Report of Dr. Dennis Lettenmaier, February 29, 2016, FX-793 at 31-33.)

53. Nor are these fundamental changes due to declining natural recharge (*i.e.*, precipitation that enters the aquifer). For a similar natural supply of water to the aquifer, low baseflow is more common and severe in recent decades. Figure 8 shows calculated natural recharge to the Upper Floridan Aquifer from 1915-2013; the recharge values are from the production in support of Dr. Hornberger's February 29 Expert Report. Figure 8 shows that recharge varies from year to year, but there has been no long-term declining trend. In fact, there is a slight upward trend in the recharge rate from 1915-2015.

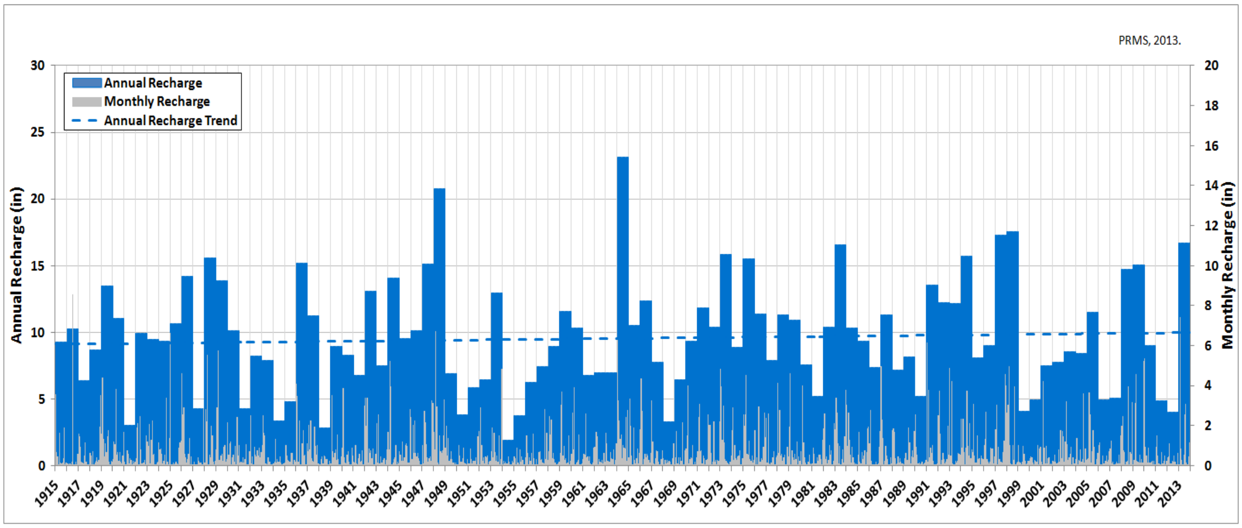


Figure 8. Plotting monthly and annual recharge data produced in support of Dr. Hornberger's February 29, 2016 Expert Report, FX-785, and including a best-fit (dashed-blue) line through the annual recharge data, indicating a slight upward trend in recharge rates from 1915-2013.

54. In contrast to precipitation and recharge, which have remained stable, Georgia's groundwater pumping has increased significantly since the 1970s. (Hornberger Report at 27-32.) Georgia pumping now consume much of the water that would otherwise replenish the Upper Floridan Aquifer, especially during drought periods

55. Prior to 1970, pumping rates in Georgia portion of the ACF Basin were negligible (Expert Report of Dr. Samuel Flewelling (February 29, 2016), FX-786 ("Flewelling Report").). Accordingly, the ratio of pumping-to-recharge would have been approached zero (meaning that virtually none of the water replenishing the Upper Floridan Aquifer would have been consumptively used for irrigation.)

56. To evaluate the impacts of pumping in the early 1980s, Hayes *et al.* (1983) developed a numerical-simulation model that examined the relationship between recharge and pumping. (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.)

Hayes *et al.* (1983) estimated that, during the early 1980s, average pumping conditions led to the withdrawal of approximately 10% of natural baseflow (which is approximately equal to recharge). They concluded that those withdrawals rates would not cause long-term groundwater-level declines in the Upper Floridan Aquifer.

57. Compare recent drought-year pumping rates with those Hayes *et al*. examined in the early 1980s and the fact that pumping was negligible prior to 1970. During recent drought years (1999, 2000, 2006, 2007, 2011, and 2012), irrigation pumping has consumed approximately half of the recharge (45-50%) that would have otherwise replenished the Upper Floridan Aquifer.

58. By consuming much of the water that would naturally replenish the aquifer—particularly during drought—Georgia significantly contributes to the declining groundwater-level trends I discuss above.

59. What's more, the Upper Floridan Aquifer pumping estimates upon which I have based my calculations come from Georgia's self-reported data and are necessarily underestimates. Thus it is likely that actual pumping rates, and their corresponding impacts, are significantly higher. (Flewelling Report at 8-9.)

60. Baseflow during recent droughts is lower than in comparable or worse historical droughts that occurred during the pre-irrigation period (*i.e.*, prior to the 1970s). Analysis by the Georgia State Geologist, Dr. Kennedy, supports this opinion. (Panday Tr. (August 1, 2016), Ex. 13 (October 31, 2011 Memorandum by Dr. James L. Kennedy, Georgia Geologist) ("Kennedy Memo".) For example, in 1954, precipitation and groundwater-recharge rates reached record lows—the lowest values on record (between 1915 and 2013). Dr. Kennedy evaluated baseflow at the Milford gage on the Ichawaynochaway Creek and the Iron City gage on Spring Creek to

determine the number of months in each year when measured baseflow was extremely low—*i.e.*, within the 10th percentile of the lowest baseflow values measured at those two gages between 1954 and 2010. (Kennedy Memo.) In 1954—again, the drought of record—Dr. Kennedy counted ***only six*** such extremely low-flow months for the two gages combined.

61. Since the 1980s, extremely low baseflow has occurred at a much greater frequency. The table below summarizes the number of extremely low baseflow months identified by Dr. Kennedy at those same two gages.

Year	Number of Extremely Low Baseflow Months
1986	12
1990	7
2000	14
2001	7
2002	6
2007	14

All of these years post-date Georgia's widespread implementation of intense agricultural pumping from the Upper Floridan Aquifer. And each of these years experienced more rainfall and recharge than in 1954. In other words, baseflow has been lower in recent years even though the natural supply of water has been larger. Further, his analysis extended only through 2010. Had Dr. Panday used the same procedures to evaluate 2011 and 2012, he would have identified more extremely low flow months in those years than in 1954. These data provide yet additional evidence that Georgia pumping adversely impacts baseflow, and hence streamflow.

62. The impacts of pumping, as distinguished from just drought, can also be seen in the shift of the low baseflow months to earlier in the year since the advent of intense widespread agricultural pumping. Under natural conditions, the lowest baseflow tends to occur in the fall, typically October or November. Under the influence of agricultural pumping, the occurrence of low baseflows has shifted earlier in the year, into the months when pumping for the growing

season starts. (Kennedy Memo; Langseth Dep. Tr. (August 18, 2016), Ex. 45, 1172:08–1174:11, FX-593.)

63. By consuming the groundwater that would otherwise be available to naturally recharge and replenish the Upper Floridan Aquifer, Georgia reduces baseflow. Dr. Kennedy's analysis and the hydrologic data alone establish this impact is real. Modeling studies, discussed below, can also be used to estimate these impacts quantitatively.

64. The amount of water Georgia withdraws from the Upper Floridan Aquifer through agricultural pumping may be put into perspective by comparing that pumping with Lake Lanier. Using conservatively low estimates, agricultural pumping from the Upper Floridan Aquifer in 2010, 2011, and 2012 totaled approximately 1,275,000 acre feet—an amount that is 15% greater than the entire conservation volume of Lake Lanier (1,087,600 acre feet).

C. Georgia has repeatedly acknowledged the damaging impacts of pumping on streamflow.

65. As hydrologists routinely do, and as I have done in the normal course of my practice, I also reviewed and relied upon findings of government agencies and scientists. Based on my review of Georgia documents, it is apparent that Georgia has long recognized that its agricultural pumping adversely impacts the Flint River.

66. In the Flint River Basin Regional Water Development and Conservation Plan ("Flint River Plan"), Georgia's Department of Natural Resources found that agricultural withdrawals in the Upper Floridan Aquifer in the Flint River Basin "reduce streamflow, and can degrade aquatic habitat in the lower FRB." (GADNR, Flint River Plan, 2006, JX-21 at 15-16.) Georgia further concluded that "[s]urface-water and ground-water withdrawals in the FRB can have a negative impact on stream ecology and the viability of sensitive aquatic species." (*See* Langseth Report at 46.)

67. According to Georgia "the amount of water *currently* withdrawn for agricultural irrigation in drought years increases both the magnitude and duration of low flows in streams of the FRB, thus further harming endangered species and potentially limiting the amount of water available for all users. This is especially true in Spring Creek and Ichawaynochaway Creek sub-basins. Expanded drought-year irrigation will worsen this situation; reduced irrigation will improve it." (GADNR, Flint River Plan, 2006, JX-21 at 51 (original emphasis); Langseth Report at 46.)

68. According to Georgia, "[s]ince extensive development of irrigation in the lower Flint River Basin, drought-year flows are reached sooner and are lower than before irrigation became widespread. Furthermore, low-flow criteria established by the U.S. Fish and Wildlife Service designed to protect aquatic habitats are not met more frequently and for longer periods of time since development of irrigation." (GADNR, Flint River Plan, 2006, JX-21 at 22; Langseth Report at 46.)

69. The 2011 Lower Flint-Ochlockonee Regional Water Plan ("LFO Plan") similarly recognized that "[i]n the Upper Floridan Aquifer in the Dougherty Plain, the impact of groundwater withdrawals on surface water flows in the Flint River Basin should be a determining factor in guiding the location and amount of groundwater use from this aquifer." (LFO Plan, 2011, FX-24 at ES-4; Langseth Report at 46.) In a technical memorandum, the LFO Plan built on this finding, identifying "irrigation suspension" as a "tool needed to sustain in-stream flow in particularly dry periods." (GADNR, Technical Memo, 2011, FX-617 at 13; Langseth Report at 46.)

70. In a 2011 memorandum, Georgia EPD hydrologist Dr. Wei Zeng concluded that 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." (GADNR, Zeng Memo, 2011, FX-82 at 1; *see also* Liang Exhibit 36, Deposition of Liang, Feb. 9, 2016, 162:06–163:17.) Dr. Zeng found that, when compared with the two previous drought years (2007 and 2008), "the lack of groundwater recovery" in 2011 was "stunning." (*Id.*) Dr. Zeng observed that the historical record of daily low flows had been broken, and that "low groundwater level and discharge has shown its effects on streamflow." (*Id.*)

71. Upon evaluating the impacts of pumping on groundwater levels and streamflow, Mr. Woody Hicks—a former USGS hydrologist who studied the hydrology of the ACF Basin for over 30 years—reached similarly dire conclusions. According to Mr. Hicks, "[o]ur groundwater levels suffer from heavy irrigation pumping, particularly during drought." He found that "[f]lows in the lower Flint have declined in response to reduced inflow from the upper Flint and to agricultural withdrawals from the aquifers, which reduce inflow to river, and from streams, which have a direct effect on the resource." Recognizing how ACF Basin hydrology has fundamentally changed since the widespread use of high-intensity irrigation, Mr. Hicks observed that "[m]any streams in the lower Flint drainage have experienced severe reductions in short-term and long-term flow." The cause of these reductions was as obvious to Mr. Hicks as it is to me: "The combined effects of irrigation pumping and drought create non-flowing conditions that did not exist prior to the late 1990s." (Langseth Report at 47 (quoting Hicks, D.W., *et al*, "Geohydrology of the Albany Area, Georgia," GADNR, Georgia Geologic Survey Information Circular 57 at 43).)

VI. EVERY GALLON OF WATER PUMPED IN THE UPPER FLORIDAN AQUIFER ULTIMATELY RESULTS IN A STREAMFLOW DEPLETION OF NEARLY 0.90 GALLONS; SHORT-TERM STREAMFLOW DEPLETIONS RANGE FROM A CONSERVATIVE LOW OF 0.41 GALLONS TO ABOUT 0.60 GALLONS.

A. Groundwater models can be used to determine the relationship between groundwater withdrawals and streamflow depletions.

72. Hydrologists commonly employ hydrologic models to estimate the impacts of groundwater pumping on streamflow reductions (direct measurements of streamflow depletion are uncommon). (Langseth Report at 36.) While these models are useful tools for indirectly quantifying groundwater flow, when evaluating model results, hydrologists must always account for uncertainties inherent in model simulations and consider the particular attributes of the hydrologic system under evaluation. (*Id*. at 40.)

73. Groundwater pumping does not immediately impact streamflow. Depending on a well's proximity to a stream, there can be a time lag between when water is withdrawn and when streamflow depletions materialize. (*Id*. at 27.) These time lags apply even with respect to what I refer to as "short-term" impacts, and can be accounted for in hydrologic simulation models.

74. When evaluating the impacts of groundwater withdrawals on surface water flows, hydrologists commonly analyze the relationship between pumping rates and streamflow depletions by calculating the ratio between streamflow depletion and pumping rates, a ratio I call an "impact factor." (*Id*. at SS-7.) (In this case, the terms "streamflow reduction factor" ("SRF") "annual connectivity factor" have also been used to describe this ratio of pumping rates to streamflow depletions.) An impact factor can be represented as either a fraction or a percentage. For example, an impact factor of 60% means that for every 1.0 gallon of water pumped, 0.60 gallons are removed from streamflow in the short term (days to a few months).

B. The total long-term impact factor in the Upper Floridan Aquifer is nearly 90%.

75. Based on my evaluation of numerical modeling studies of the Upper Floridan Aquifer, the total long-term impact factor in the Georgia portion of the ACF Basin is nearly 90%. This means that, over a long-term period, pumping 1.0 gallon of groundwater reduces streamflow by almost 0.90 gallons. The full realization of this impact will not occur until groundwater levels and soil-moisture storage return to their pre-pumping equilibrium levels. Additionally, before regaining equilibrium, the lower groundwater level causes continued baseflow reduction even in the absence of more pumping, as described earlier. (Langseth Pumped Water Source Notes, FX-585 at 1; Langseth Dep. Tr. 1023:21–1024:13 (August 16, 2016).)

76. Fundamental hydrologic principles support my conclusion that the total long-term impact factor in the Georgia portion of the ACF Basin is 90% or higher. In a fully closed system, the total impact factor for consumptive use withdrawals would approach 100%. By contrast, the total impact factor for the Upper Floridan Aquifer in the ACF Basin approaches, but not reach, 100% because a portion of the pumping impact occurs outside the ACF Basin. In the Lower Flint River Basin, Upper Floridan Aquifer pumping may reduce streamflows in other watersheds (*i.e.*, not within the boundaries of the ACF Basin). According to at least one study by the Georgia Geological Survey, however, long-term impact factors in the ACF Basin are nearly 1.0, meaning that nearly all the pumped water produces streamflow depletions. (Hayes *et. al*, 1983.)

C. Groundwater models and hydrologic observations indicate that short-term impact factors range from a conservative low of 41% to a more realistic value of 60%.

77. In my expert report, I evaluated pumping-related streamflow depletions in the ACF Basin primarily by relying on published model results from the Jones and Torak model (2006). I noted in my report that the results from the Jones and Torak model for the short-term impact factor are conservative, meaning that they understate the short-term impacts of pumping. (Langseth Report at SS-7.) Although I used the Jones and Torak model results in my calculations, I recognized that my reliance on the Jones and Torak model would result in conservative short-term impact calculations, meaning they would necessarily understate the rate at which groundwater withdrawals reduce streamflow. (*Id*. at SS-7, SS-8, 40, 51-52, E-9, E-10.)

78. I concluded that groundwater pumping in the Upper Floridan Aquifer conservatively produces a short-term annual average impact factor of 41%, which means that for every 1.0 gallon of water pumped from the aquifer, short-term streamflow depletions are at least 0.41 gallons. Based on my review of the available data and modeling, it is my opinion that the short-term impact factor ranges from at least 41% to a more realistic 60%. (Langseth Dep. Tr. 1161:11-15 (August 18, 2016); Langseth Report, Appendix D at D-5.) Basic data analysis, fundamental hydrologic principles, and the limitations of the various models all indicate that the annual short-term impact factor is at the higher end of the range of reported values. For a number of reasons, they also confirm my opinion that a 41% impact factor understates the impacts of groundwater withdrawals on streamflow depletions. (*E.g.*, Langseth Report at 51-52.)

79. For example, the Flint River Basin has experienced large declines in streamflow and baseflow that are not explained by climate variation. (Hornberger Report, FX-785 at 27-37.) According to Dr. Hornberger's analysis of publicly available data, modern droughts produce significantly less streamflow than historic droughts. (Hornberger Report, FX-785 at Section IV,

14-26.) The absence of long-term climate change during this period indicates these significant streamflow losses include impacts from groundwater withdrawals that deplete streamflow at a higher rate than 41%. (Hornberger Report, FX-785 at Section V(a), 27-32.) Such a low impact factor does not fully account for the large streamflow declines observed in the raw data.

80. Others who have studied this issue have employed different, yet reliable, models to derive a range of impact factors—most of them higher than 41%. For example, in 1998, Georgia's expert, Dr. Panday, calculated an impact factor of about 60% or higher for the Upper Floridan Aquifer, using a model calibrated to October 1986 conditions. Also, the Georgia Environmental Protection Division simulation for 2011 pumping conditions 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%).)

81. The transient simulation prepared by Jones and Torak for March 2001-February 2002 does not simulate baseflow well. (Langseth Report, FX-795 at 51.) This simulation underestimates baseflow in the early months of the simulation and overestimates baseflow in the later months of the simulation. These anomalous results are consistent with streamflow-impact factors that are too low.

D. Impact factors can be used to calculate the effects of pumping on streamflow at different times.

82. In a typical year, agricultural-pumping rates in the ACF vary by month and season, often in a consistent pattern or schedule. Figure 9 illustrates a representative pumping schedule for the Upper Floridan Aquifer in the ACF Basin within Georgia.

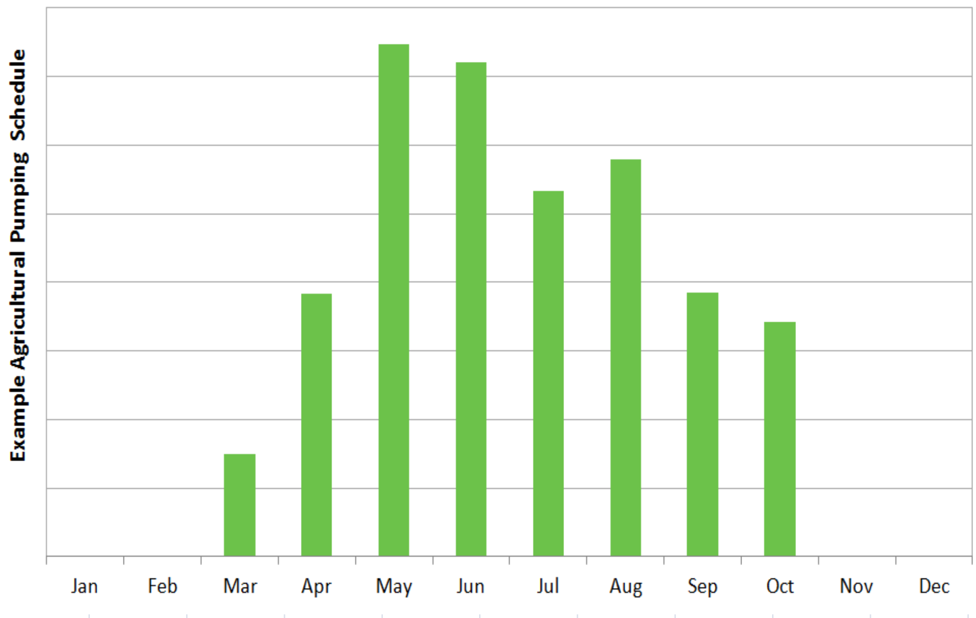


Figure 9. Representative Drought Year Agricultural Pumping Schedule from the Upper Floridan Aquifer in the ACF Basin within Georgia (Langseth Report, Appendix E).

83. Streamflow impacts vary by time of year. Therefore, it is helpful to compare streamflow-depletion rates in particular months with average annual streamflow-depletion rates. The ratio reflecting this comparison may be called a "seasonal factor."

84. Dr. Panday's 1998 modeling resulted in a seasonal factor for June of about 2.3. This means that the average streamflow depletion in the month of June was 230% greater than the average streamflow depletion for the entire year. The 2.3 seasonal factor is consistent with the seasonal factor for June calculated by Dr. Hornberger. (*See* Hornberger Report, FX-785 at 94, Table D.2.)

85. As an example of how these annual impact and seasonal factors are used, consider the 2007 pumping from the Upper Floridan Aquifer in the Lower Flint River Basin. For that year, I conservatively estimated the 12-month average Upper Floridan Aquifer pumping rate to be 754 cfs, and the peak average monthly rate (for May 2007) to be about 1,950 cfs. Using Dr. Panday's model results, a 60% average annual short-term impact factor means that the average

annual short-term streamflow depletion would be 452 cfs (60% x 754 = 452 cfs). Applying the seasonal factor of 2.3 for June, the streamflow depletion in June would be 2.3 x 452 = 1040 cfs. Thus, using conservative pumping assumptions, short-term streamflow depletions from pumping only the Upper Floridan Aquifer (in June 2007) are over 1,000 cfs.

86. If Georgia were to permanently reduce irrigation pumping, the beneficial streamflow impacts would be substantial. Regardless of where pumping occurs within the Lower Flint River Basin, over the long term, the beneficial impacts on streamflow would approach 90% of the total decreased pumping. Especially for those wells located in close proximity to streams, the beneficial impacts from reduced pumping would be greatest during those months when streamflow levels are at their lowest.

87. Hydrologic connections between streamflow and pumping from the other aquifers exist, but are not as strong as the connection from the Upper Floridan Aquifer. (Langseth Report at 5, 16-17, 37.) Relying on published data and hydrologic principles, I estimate short-term impact factors of approximately 30% for the Claiborne Aquifer and about 20% for the Clayton and Cretaceous Aquifers of about 20%. (*Id*. at E-12.) The literature and basic hydrologic principles support higher impact factors for these aquifers. (*Id*. at E-10.)

88. The pumping estimates in my expert report are limited to pumping from only the Upper Floridan Aquifer within the Jones and Torak model domain; they did not include pumping from other aquifers or pumping from outside the model domain. They also do not include irrigation from surface water sources, which constitutes approximately 22% of irrigation in Georgia and has a 100% impact factor (for every gallon of surface water removed for irrigation, a gallon of streamflow depletion occurs).

89. I used a very conservative method for estimating how much water was pumped from the Upper Floridan Aquifer, as I needed only a lower bound on that value for the evaluations I performed in my report. That evaluation was for a hydrologically efficient method of reducing pumping impacts on streamflow, in which I showed that by selecting locations at which to reduce pumping where I know the local impact factor to be higher than the system-wide average, the short-term impact factor could be increased above the value of 0.41 that would accrue if pumping were reduced uniformly at all pumping locations. The logic behind this approach would be to reduce pumping where those reductions maximize streamflow benefit—all other things being equal.

90. I further presented a very conservative evaluation of impacts, based on an approach applying a system-wide, conservative impact factor of 41% for the current pumping distribution, and also not accounting for additional impacts associated with long-term water table declines or of multi-year droughts.

VII. THE IMPACT OF GROUNDWATER PUMPING ON STREAMFLOW INCREASES DURING MULTI-YEAR DROUGHTS

91. The short-term impacts of pumping on streamflow in the second and subsequent years of a multi-year drought are greater than in the first year. (Langseth Report at SS-6, 32-33 (citing Peck *et al.*, which "illustrates the strong impact of two consecutive severe drought years), 48-49 (citing Hayes *et al.*, 1983 and Zeng & Kim, 2011).)

92. This follows from basic mass-balance principles. All pumped water must come from either reduced streamflow, increased recharge or reduced storage. If reduced storage is not replenished between growing seasons, an aquifer starts in a depleted condition, with lower water levels, at the beginning of a second or third drought year. For the aquifer, this means that baseflow rates entering the growing season are lower than they would otherwise be.

93. Droughts stress groundwater resources and limit the baseflow that sustains streamflow when it is not raining. These stresses occur in at least three ways, and compound significantly during multi-year drought periods.

94. First, rain is limited during drought (by definition). When it is not raining, there is little precipitation available to recharge aquifers and replenish groundwater supplies.

95. Second, smaller proportions of the precipitation that does occur during droughts ends up recharging the aquifers; in other words, during droughts, the Upper Floridan Aquifer receives a smaller share of precipitation than during wetter periods. During droughts, more of the rain is absorbed by dry soil and plants in need of water, more of the rain evaporates and transpires, and less of the rain migrates down to the aquifer. In hydrological terms, recharge rates as a proportion of precipitation decline in drought years because actual evapotranspiration rates consume higher percentages of precipitation.

96. Third, agricultural-pumping rates increase during droughts because farmers turn to irrigation to sustain their crops. In fact, pumping rates increase in proportion to drought severity—the more dry it is, and the longer a drought wears on, the more water is pumped. To the extent pumping rates increase, so do the adverse impacts on groundwater levels.

97. These three stresses on groundwater supplies are even further exacerbated during multi-year droughts. In the subsequent years of a multi-year drought (*e.g.*, the second or third year), groundwater elevations begin at relatively low levels. Whereas aquifers may recover when a drought ends (to the extent storms bring enough rain to recharge the aquifer to its preexisting condition), when drought conditions persist from one year to the next, the three above-described stress factors combine to drive groundwater levels down even further.

98. 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 (i.e., the recharge rate was 25%). The year 2010 was somewhat drier: the recharge rate in the Upper Floridan Aquifer was approximately 21%. Severe drought commenced in 2011, however, and continued through much of 2012. As a result, recharge rates fell to 13%, and then 10%, of precipitation, respectively. In addition to experiencing very low recharge rates, the Upper Floridan Aquifer was pumped intensely during that period: agricultural withdrawals consumed about 45% of the diminished recharge during each of 2011 and 2012. Accordingly, groundwater levels declined precipitously. *See, e.g.*, Peck *et al.* (2013) JX-83 at 21 (identifying groundwater-level declines above 17 feet in the Upper Floridan Aquifer).

99. 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 (*see, e.g.*, my testimony regarding 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. SIMILAR STREAMFLOW IMPACTS DO NOT OCCUR IN THE FLORIDA PORTION OF THE ACF BASIN

100. In Dr. Panday's expert report, he claimed water losses in the Apalachicola basin upstream of the Sumatra gaging station ranging from about 3,000 to nearly 10,000 cfs, without postulating a reason for these losses.

101. I conducted an analysis that showed that Dr. Panday's water-loss estimates are highly flawed. (Langseth, Panday Water Budget Evaluations, June 28, 2016, FX-805.) Dr.

Panday made several fundamental errors. Among these, he improperly (1) double-counted flow on the Apalachicola River by failing to account for the Chipola River Cutoff, which connects the Chipola River and the Apalachicola River, (2) overestimated the relevant watershed area, resulting in additional double-counting, (3) failed to account for natural evapotranspiration, and (4) used uncorrected flows reported from the Sumatra Gage. When these errors are corrected, the water-budget analysis for the Apalachicola basin does not show the losses Dr. Panday claims.

102. Dr. Panday also claimed that the Apalachicola River was a "losing reach" with respect to groundwater. (*Id*. at 1.) My analysis of groundwater contour maps shows that Dr. Panday is incorrect: the Apalachicola River is generally gaining. (*Id*. at 1-2.) At his deposition, Dr. Panday acknowledged that groundwater contours indicate that the Apalachicola River is generally gaining with respect to groundwater, at least as far downstream as the Blountstown gage (river mile 77.5 on the Apalachicola River). (Panday Tr. (August 1, 2016) at 260:5–24.)

103. Independent experts have reached similar findings to mine. Consistent with my analysis, Torak and McDowell (1996 p. 59 USGS OFR 95-321) show that the Apalachicola River is gaining even further downstream (JX-7). At or downstream of the Sumatra gage, the River and groundwater levels are at similar elevations. This means that the Apalachicola River between the Sumatra gage and the coast is neither gaining nor losing, but essentially level with the groundwater as both make their way to the Apalachicola Bay.

IX. TRIAL EXHIBITS CITED IN MY TESTIMONY

104. FX-002 is a true and accurate copy of a document bearing the Bates No. GA02257043-50 and identified as a June 1, 1999 Memorandum from EPD Director Harold Reheis to a Mr. James E. Butler, Jr. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

105. FX-024 is a true and accurate copy of a document titled, “September 2011 Lower-Flint Ochlockonee Regional Water Plan,” which is publicly available at http://www.flintochlockonee.org/documents/LFO_Adopted_RWP.pdf. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

106. FX-082 is a true and accurate copy of a document bearing the Bates No. GA01614062-76 and identified as a September 6, 2011 Memorandum from Wei Zeng to Allen Barnes. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

107. FX-548 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology, including standard hydrologic and statistical analysis. The document compares groundwater trends at a specific Upper Floridan Aquifer monitoring well. At my direction, the USGS well data underlying these comparisons were collected from reliable and publicly available sources, which are the type of data regularly relied upon by experts in my field.

108. FX-549 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology, including standard hydrologic and statistical analysis. The document compares groundwater trends at a specific Upper Floridan Aquifer monitoring well. At my direction, the USGS well data underlying these comparisons were collected from reliable and publicly available sources, which are the type of data regularly relied upon by experts in my field.

109. FX-550 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology, includingstandard

hydrologic and statistical analysis. The document compares groundwater trends at 18 specific Upper Floridan Aquifer monitoring wells. At my direction, the USGS well data underlying these comparisons were collected from reliable and publicly available sources, which are the type of data regularly relied upon by experts in my field.

110. FX-551 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology, including standard hydrologic and statistical analysis. The document provides statistical analysis of data from 20 Upper Floridan Aquifer monitoring wells. At my direction, the USGS well data underlying these comparisons were collected from reliable and publicly available sources, which are the type of data regularly relied upon by experts in my field.

111. FX-552 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology. The document provides summary statistics for 20 Upper Floridan Aquifer monitoring wells. At my direction, the USGS well data underlying these comparisons were collected from reliable and publicly available sources, which are the type of data regularly relied upon by experts in my field.

112. JX-18 is a true and accurate copy of a USGS document titled, "Simulated Effects of Seasonal Ground-Water Pumpage for Irrigation on Hydrologic Conditions in the Lower Apalachicola–Chattahoochee–Flint River Basin, Southwestern Georgia and Parts of Alabama and Florida, 1999–2002," authored by L. Elliott Jones and Lynn J. Torak, and dated 2006 ("Jones and Torak (2006)"). This document is publicly available on the USGS website at http://pubs.usgs.gov/sir/2006/5234/pdf/sir2006-5234.pdf. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

113. FX-585 is a true and accurate copy of a document titled, "Langseth Pumped Water Source Notes" that I prepared and discussed during my August 18, 2016 deposition. This document was introduced as Ex. 36 during that deposition.

114. FX-593 is a true and accurate copy of a document, prepared at my direction and employing generally scientifically accepted principles and methodology, including standard hydrologic analysis (the USGS PART Method). The document replicates the baseflow estimates (at the Newton Gage in the Flint River Basin) that Dr. James Kennedy provided for the years 1957 to 2010 based on application of the USGS PART method. This document supplements Dr. Kennedy's baseflow estimates for the years 2011 to 2015, which are highlighted in yellow.

115. FX-629 is a true and accurate copy of a document titled "Estimate of Agricultural Water Use and Consequent Reduction in Stream Flow - Georgia EPD Hydrology Unit," by Georgia EPD and dated January 2012. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case

116. FX-785 is a true and accurate copy of the Expert Report of Dr. George Hornberger (February 29, 2016) ("Hornberger Report"). It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

117. FX-786 is a true and accurate copy of the Expert Report of Dr. Samuel Flewelling (February 29, 2016) ("Flewelling Report"). It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

118. FX-793 is a true and accurate copy of the Expert Report of Dr. Dennis Lettenmaier (February 29, 2016) ("Lettenmaier Report"). It is the type of information regularly

relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

119. FX-795 is a true and accurate copy of the expert report that I prepared and submitted on February 29, 2016 ("Langseth Report").

120. FX-805 is a true and accurate copy of a memorandum dated June 28, 2016 with the subject, "Dr. Panday Water Budget Evaluations" that I prepared and submitted to Dr. George Hornberger.

121. JX-7 is a true and accurate copy of a 1996 USGS report (Open File Report 95–321) authored by Lynn J. Torak and Robin John McDowell titled, "Ground-Water Resources of the Lower Apalachicola-Chattahoochee-Flint River Basin in Parts of Alabama, Florida, and Georgia—Subarea 4 of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins." It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

122. JX-21 is a true and accurate copy of the March 20, 2006 Flint River Basin Regional Water Development and Conservation Plan, authored by the Georgia Department of Natural Resources EPD, which is publicly available on a Georgia EPD website: https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/Plan22.pdf. It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

123. JX-54 is a true and accurate copy of a 2012 USGS report (Scientific Investigations Report 2012–5179) authored by Debbie W. Gordon, Michael F. Peck, and Jamie A. Painter titled, "Hydrologic and Water-Quality Conditions in the Lower Apalachicola-Chattahoochee-Flint and Parts of the Aucilla-Suwannee-Ochlockonee River Basins in Georgia

and Adjacent Parts of Florida and Alabama During Drought Conditions, July 2011." It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.

124. JX-83 is a true and accurate copy of a 2013 USGS report (Scientific Investigations Report 2013–5084) authored by Michael F. Peck, Debbie W. Gordon, and Jamie A. Painter titled, "Groundwater Conditions in Georgia, 2010–2011." It is the type of information regularly relied upon by experts in my field, and I reviewed and relied upon it in forming my opinions in this case.