No. 142, Original

In The
Supreme Court of the United States

STATE OF FLORIDA,

Plaintiff,

v.

STATE OF GEORGIA,

Defendant.

DIRECT TESTIMONY OF SORAB PANDAY, Ph.D.

October 26, 2016

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I. INTRODUCTION AND OVERVIEW

1. I, Sorab Panday, Ph.D., offer the following as my Direct Testimony.

2. I am an expert in hydrogeology, groundwater modeling, and modeling of groundwater/surface-water interactions. I have been retained by the State of Georgia to analyze the impact of groundwater pumping in Georgia on streamflow in the Apalachicola-Chattahoochee-Flint ("ACF") River Basin. I have also been asked to review and consider the expert reports and testimony submitted by Florida's experts as it relates to impacts of groundwater pumping in the ACF River Basin—specifically Drs. Langseth, Hornberger, and Sunding.

3. In forming my opinions, I conducted a detailed and systematic review of data, existing literature, reports, and modeling studies of groundwater, and the aquifer-stream interactions in the ACF River Basin. In addition to the literature review, I conducted extensive independent hydrogeologic (groundwater) modeling simulations to determine the impact of groundwater pumping on groundwater levels and streamflow in the ACF River Basin. As part of that process, I have reviewed data regarding the hydrology, hydrogeology, and weather patterns of the ACF River Basin. I have also performed an assessment of water withdrawals for agricultural and municipal and industrial uses in the ACF River Basin. I then used those data as inputs into verified, calibrated groundwater models to evaluate the impact of pumping on groundwater flow to rivers and streams of the ACF River Basin.

II. SUMMARY OF OPINIONS

4. Groundwater pumping in the Lower ACF River Basin in Georgia has a minimal impact on streamflow at the Florida Georgia State Line, even during periods of drought and peak irrigation when flows are at their lowest and agricultural water use is at its highest.

i) Numerical modeling is the best and most accurate way to calculate the impact of groundwater pumping on streamflow in the ACF River Basin. I rely on the Jones and Torak MODFE model which was designed by the United States Geological Survey (USGS) (the federal agency with expertise in assessing streamflow impacts from agricultural pumping) and Georgia Environmental Protection Department (EPD), specifically to assess the impact of pumping from the Upper Floridan Aquifer (UFA) on streamflow.

ii) My independent numerical modeling analyses shows that streamflow reductions caused by groundwater pumping from the Upper Floridan Aquifer ("UFA") in Georgia are minimal compared to state-line flow into the Apalachicola River. Even during the driest month of an extreme drought, when impacts from pumping are typically greatest, the impact of all pumping in the Lower ACF River Basin on streamflow was equivalent to approximately 10% of the minimum monthly flow into the Apalachicola River.

iii) Weather conditions and natural hydrologic factors have a far greater impact on streamflow rates into Florida and their fluctuations, than groundwater pumping.

iv) While groundwater pumping in the Lower ACF River Basin has increased since 1992, this increase has had a negligible cumulative impact on streamflow.

v) Pumping from aquifers other than the UFA in the entire ACF River Basin has a negligible impact on streamflow with a peak monthly impact of around 21 cfs.

5. The Apalachicola River Basin from the Chattahoochee Gage to the Sumatra Gage within Florida is a losing reach and those losses are increasing with time.

i) Gage data shows that Florida's contribution to the Apalachicola River has been declining through time.

ii) Reductions in streamflow occurring in the Florida portion of the ACF River Basin cannot be attributed to groundwater pumping in Georgia.

6. The methodology used by Florida's groundwater expert, Dr. Langseth, which was adopted by Dr. Hornberger in his direct testimony, is flawed and exaggerates the impact of groundwater pumping on streamflow.

i) No Florida expert conducted any numerical groundwater modeling in support of their opinions concerning the impact of groundwater pumping to streamflow in this case.

Florida's groundwater analysis was incorrectly extrapolated from published papers or maps presented at professional conferences.

ii) Dr. Langseth concluded that groundwater pumping has a basin-wide annual impact of 40.6% on streamflow in his Expert Report, which is similar to my findings. That value was developed from the published results of Jones and Torak (2006) which used the most up-to-date MODFE model.

iii) However, in the current testimony, Florida rejects this 40.6% value and instead claims that the annual impact is now 60%. Florida now relies on a model developed by USGS in the 1990s to support the higher value. But USGS published an updated version of the same model in 2006 (which is the one I used for my own analysis). It is not appropriate to rely on an outdated model that used crude estimates of pumping, when the updated model was developed using statistically sound, scientifically-based evaluations of irrigation pumping from the UFA. Therefore, Florida's claim that groundwater pumping has a 60% impact is not credible.

iv) Florida's monthly distribution of pumping is not the same as that used to develop the impact factors. As a result, Florida artificially inflates monthly impacts in June and other months. Dr. Sunding relies on this inflated June value to show impossible amounts of water could be generated through conservation measures.

v) Dr. Langseth also reports what he calls a "long-term" impact factor of 90%. This amount is not based on any independent modeling and is completely unsupported.

7. There is no evidence that groundwater pumping in the ACF River Basin is causing long-term, basin-wide depletion of the UFA.

i) Lower water levels in the UFA during the dry summer months rise rapidly during the wetter winter months to about the same level each year (except during prolonged droughts). After prolonged droughts, water levels tend to recover when precipitation returns to normal. This pattern of water level fluctuations through a year can be observed in the period of record for UFA water wells, well before irrigation pumping became prevalent in the Basin.

ii) Long-term groundwater trends do not show a basin-wide trend of groundwater level decline.

iii) Increases in groundwater pumping from 1970s through the 1990s did not result in groundwater level declines.

iv) Groundwater pumping in the Lower ACF River Basin has minimal "carry-over" impact on streamflow in the following year, even during back-to-back drought years. This is because pumping is negligible in winter, and pumping-related streamflow reductions recover to nearly the same levels of the previous season after a drought year.

8. In claiming that Georgia is pumping beyond the "sustainable yield" of the UFA or impacting tributaries to the Flint River like Spring Creek, Florida focuses on local issues that have a negligible impact on the overall flow from Georgia into Florida.

i) As part of the State Water Plan, Georgia tasked a contractor to analyze how groundwater pumping from major aquifers impacted local streams and tributaries. When placed in the proper context, the "sustainable yield" for the UFA is minimally relevant to the issues in this case because the study was designed to evaluate local issues. The "sustainable yield" limit was triggered by a reduction of less than 1 cfs in streamflow caused by pumping in two very small creeks. This amount may be of local significance in the creeks that triggered the "sustainable yield" limit, but a change of less than 1 cfs is insignificant when compared to streamflow into Florida which ranges in the thousands to tens of thousands of cfs.

ii) My modeling shows that even pumping during extreme drought only reduces streamflow in Spring Creek at the Iron City Gage by around 30 cfs.

III. PROFESSIONAL QUALIFICATIONS

9. I am a groundwater hydrologist and modeler with extensive experience in the groundwater industry. During my 26-year professional career, I have developed expertise in constructing and applying models for evaluating groundwater flow and groundwater/surface water interactions.

10. I received a Bachelor's degree in Civil Engineering from the Indian Institute of Technology in Bombay, India, and a Master's degree in Civil Engineering from the University of Delaware. I received my Ph.D. in Civil and Environmental Engineering in 1989 from Washington State University, where my thesis involved development of models for complex subsurface flow and transport processes.

11. Since receiving my Ph.D., my professional career has focused on directing, managing, developing, troubleshooting, and reviewing groundwater models for hydrologic and hydrogeologic projects throughout the United States, including several basin-wide modeling projects related to groundwater/surface water interactions.

12. I am currently a Principal Engineer at GSI Environmental Inc. Many clients have relied on my groundwater modeling expertise, including private companies and government agencies such as the U.S. Environmental Protection Agency, Department of Energy, Department of Defense, the U.S. Army Corps of Engineers, and various agencies in Florida such as the St. Johns River Water Management District, the Southwest Florida Water Management District, the Northwest Florida Water Management District, Pinellas County Water System, and Seminole County.

13. I have developed several state-of-the-art groundwater modeling codes and am the lead author of the MODFLOW-USG code, which was released by the USGS in 2013.

14. I am regularly invited to participate in expert panels and to conduct workshops and webinars on water resources, subsurface flow, and transport modeling. I also frequently publish articles (and peer review submissions made by others) in industry journals, publications, and conferences.

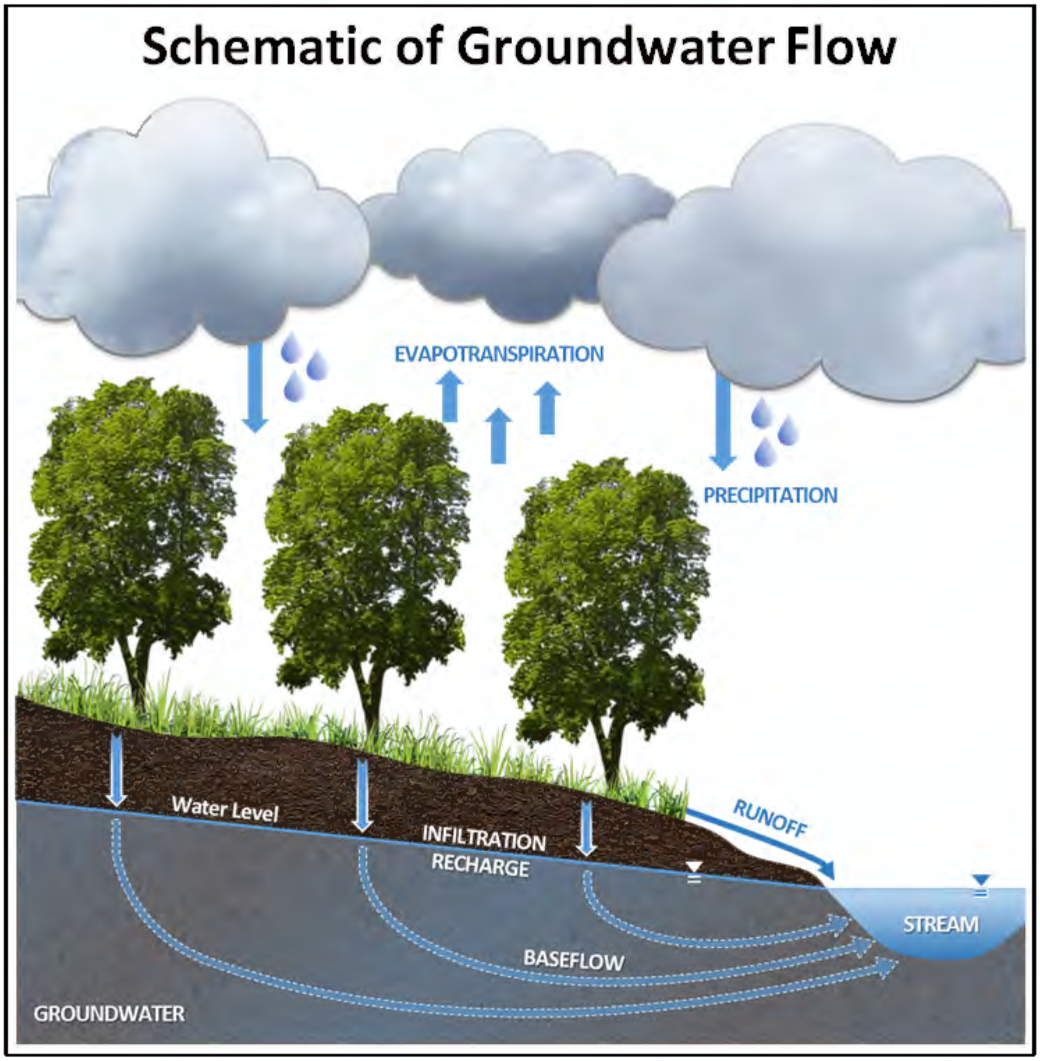
15. In 2015, the National Ground Water Association awarded me the M. King Hubbert Award for *"major science or engineering contributions to the groundwater industry through research, technical papers, teaching, and practical applications."* A true and accurate copy of my curriculum vitae can be found at GX-1026.

IV. OVERVIEW OF GROUNDWATER IN THE ACF RIVER BASIN

A. Groundwater basics.

16. Water for municipal, industrial, and agricultural irrigation in the ACF River Basin comes from two sources: groundwater and surface water. Pumping from these two sources has different impacts on stream flows. While it is assumed that pumping from surface water (such as streams and rivers) generally has a 1-to-1 and immediate impact on streamflow, pumping from groundwater does not have a 1-to-1 impact on streamflow and the timing of any impacts are usually delayed and distributed over a period of time. The magnitude and timing of impacts from pumping depends on a number of factors that I discuss throughout my testimony.

17. Groundwater is water that is held in the soil or pores and crevices in rock beneath the land surface. Panday Demo. 1 below shows a general schematic of groundwater.



Panday Demo. 1 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-1.

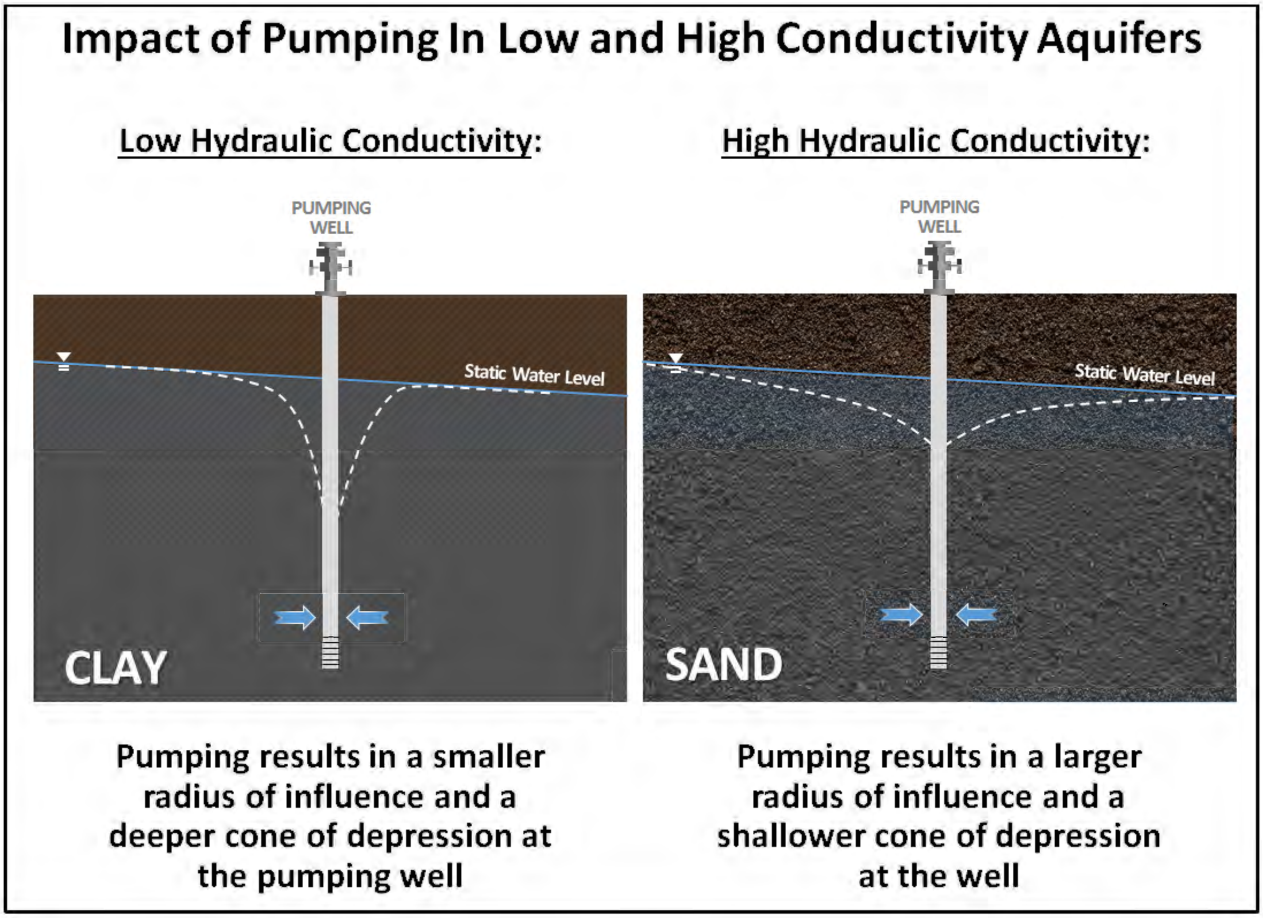
18. Groundwater generally enters the ground from precipitation seeping into the soil through a process called infiltration. The permeable subsurface units that contain and transmit groundwater are called aquifers. Water entering the aquifer is called recharge and water leaving the aquifer is called discharge. Water in aquifers discharges into water wells and surface water bodies (e.g., rivers, streams, springs, and lakes), or is lost to evapotranspiration or deeper aquifers.

19. Groundwater level is the elevation of water within an aquifer. When recharge is greater than discharge, groundwater levels rise as excess water enters aquifer storage. When discharge is greater than recharge, groundwater levels fall. Also, higher recharge causes higher groundwater levels and lower recharge causes lower groundwater levels. Groundwater levels

rise and fall cyclically through the seasons and naturally fluctuate in response to long-term weather trends like back-to-back multi-year drought periods. Pumping schedules also cause fluctuations in groundwater levels through the year.

20. The hydraulic conductivity of an aquifer describes the ease with which groundwater can flow within the aquifer. Aquifers with higher hydraulic conductivity transmit water easily, while aquifers with lower hydraulic conductivity impede the flow of water. Therefore, wells in an aquifer with higher hydraulic conductivity are more productive (i.e., produce more groundwater when pumping) than wells in an aquifer with lower hydraulic conductivity. The transmissivity of an aquifer is the hydraulic conductivity multiplied by its water-saturated thickness. Transmissivity can also be used to describe the ease with which groundwater flows through an aquifer.

21. Panday Demo. 2 below shows how the impact of pumping is more localized in an aquifer with lower hydraulic conductivity, which exhibits greater drawdown (i.e., lowering of groundwater levels) at the pumping well but with a smaller radius of influence (i.e., distance from pumping well to a point where the resulting change in water table elevation is negligible). In contrast, an aquifer with a higher hydraulic conductivity exhibits smaller drawdowns at the pumping well but with a larger radius of influence for the same rate of pumping. Thus, the impact of pumping is felt at larger distances for aquifers with higher hydraulic conductivities but drops off rapidly with distance for lower conductivity aquifers.



Impact of Pumping In Low and High Conductivity Aquifers

Low Hydraulic Conductivity:

High Hydraulic Conductivity:

Pumping results in a smaller radius of influence and a deeper cone of depression at the pumping well

Pumping results in a larger radius of influence and a shallower cone of depression at the well

Panday Demo. 2 — Impact of Pumping in Low and High Conductivity Aquifers.

B. Groundwater and streamflow.

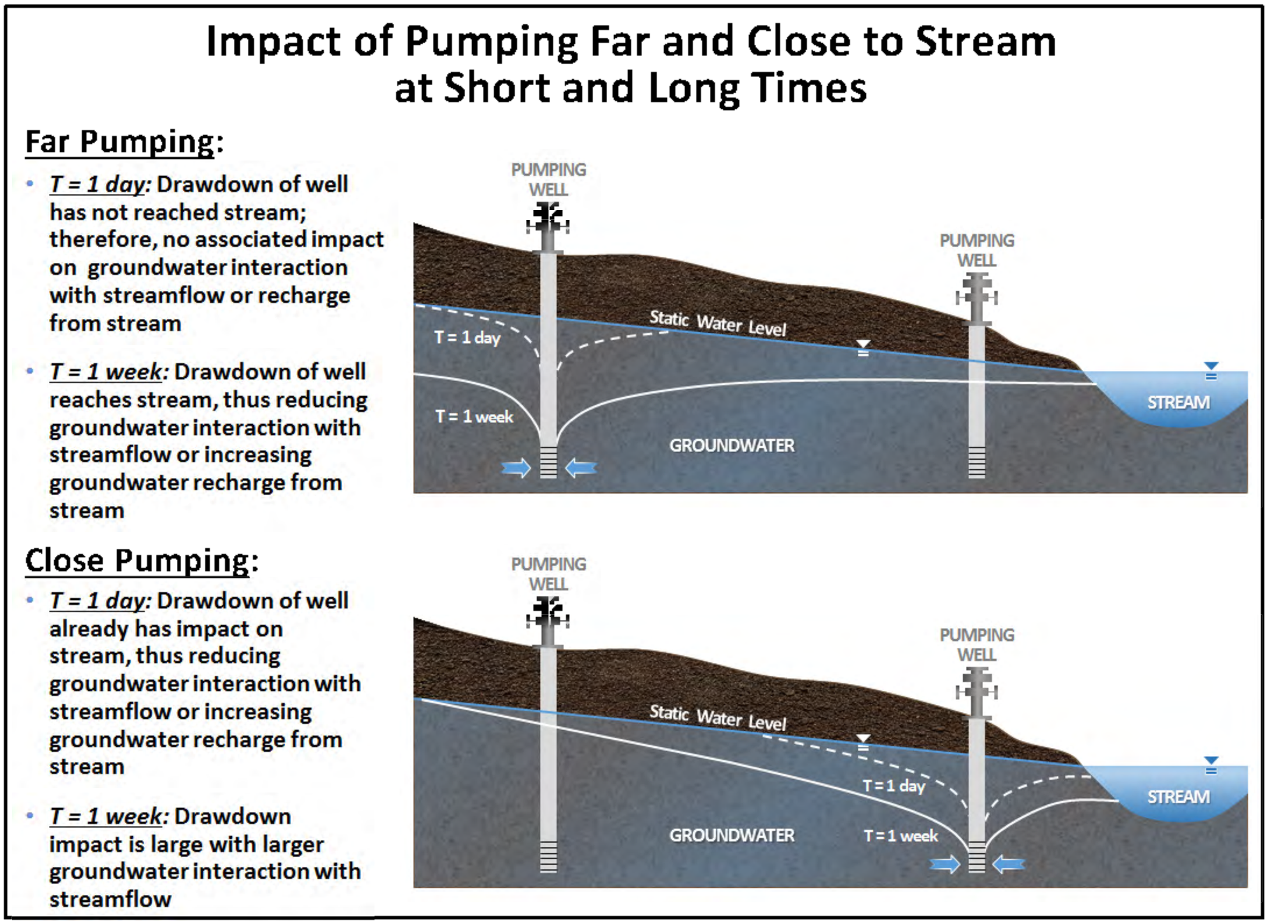
22. Streamflow is the flow of water in a river or stream at a given location. Water in streams and rivers generally comes from two sources: runoff and baseflow. Runoff is water from precipitation that does not infiltrate into the ground and flows across the land surface into streams and rivers. Baseflow is groundwater discharge into the streams and rivers. *See* Panday Demo. 1 above.

23. When groundwater levels are higher, groundwater discharge into the streams and rivers is larger (i.e., baseflow is increased). When groundwater levels are lower, groundwater discharge to streams is decreased (i.e., baseflow is reduced).

1. Impact of groundwater pumping from an aquifer

24. When groundwater is pumped from an aquifer, the pumping can have many effects. One effect is that less water flows from the aquifer to streams—this impact is the primary focus of my testimony and I refer to this as impact to baseflow—or often simply as impact to streamflow. Groundwater pumping can also cause reductions in aquifer storage as well as induced recharge into the aquifer (meaning that water is pulled into the aquifer from other sources such as the overlying aquifers or upstream areas; or water is saved through reductions in evaporation and plant transpiration).

25. The impact of groundwater pumping from a given aquifer on groundwater flow to streams, depends on the distance of the pumping well from the stream or river. Panday Demo. 3 below shows that when water is pumped from an aquifer, the impact moves outward from the pumping well location through time. Groundwater pumping close to a river impacts streamflow to a greater degree and the impacts occur more quickly than pumping farther away from the river. In addition, aquifers with larger transmissivity have a larger radius of influence; and therefore, have a higher pumping impact on streamflow than aquifers with lower transmissivity that exhibit more localized impacts. All of these factors must be taken into account to properly evaluate the impact of a particular pumping well on groundwater flow to the river. A numerical groundwater flow model accounts for the impact of all of these factors, and of pumping at a single well, as well as the impact of the interaction of multiple pumping wells extracting at different rates and locations.



Impact of Pumping Far and Close to Stream at Short and Long Times

Far Pumping:

- ***T = 1 day:*** **Drawdown of well has not reached stream; therefore, no associated impact on groundwater interaction with streamflow or recharge from stream**
- ***T = 1 week:*** **Drawdown of well reaches stream, thus reducing groundwater interaction with streamflow or increasing groundwater recharge from stream**

Close Pumping:

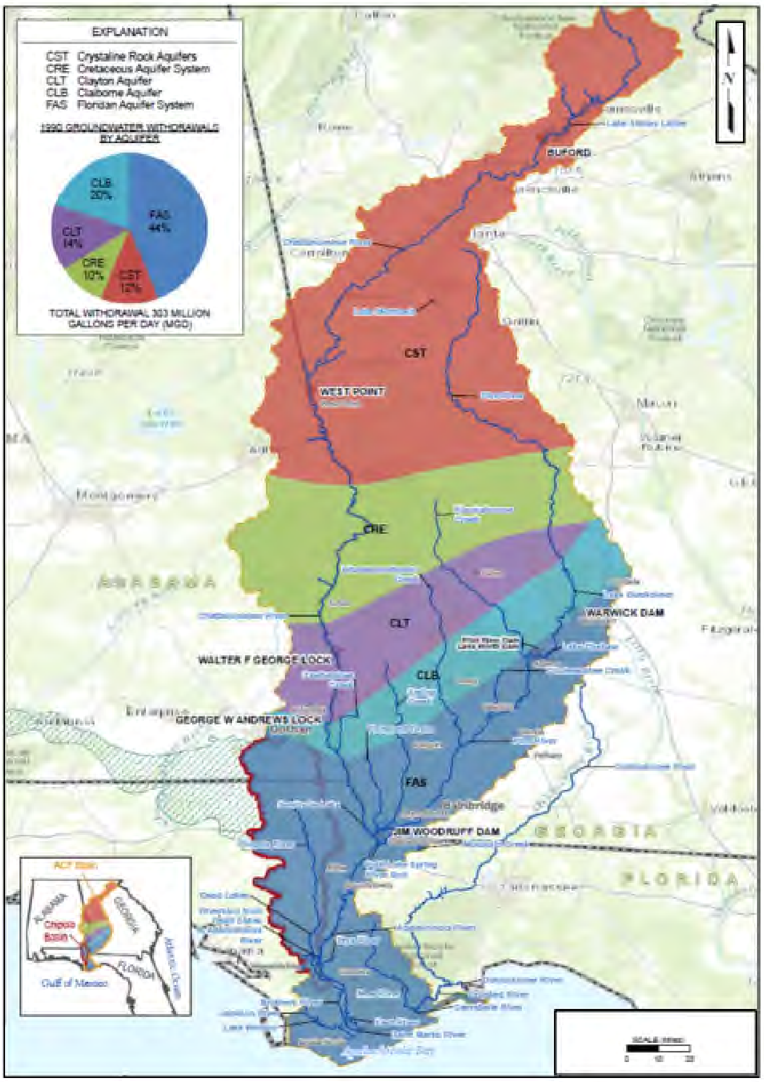
- ***T = 1 day:*** **Drawdown of well already has impact on stream, thus reducing groundwater interaction with streamflow or increasing groundwater recharge from stream**
- ***T = 1 week:*** **Drawdown impact is large with larger groundwater interaction with streamflow**

Panday Demo. 3 — Modified from Panday Expert Report, 20 May 2016, Figure 3-1.

C. Overview of the ACF River Basin and its hydrology.

26. Panday Demo. 4 below shows the five primary aquifers in the ACF River Basin: the Upper Floridan Aquifer (UFA); the Claiborne Aquifer; the Clayton Aquifer; the Cretaceous Aquifer; and the Crystalline Aquifer.

ACF River Basin Aquifers and Outcrop Areas



Panday Demo. 4 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. B-8.

1. The Upper Floridan Aquifer (UFA)

27. The UFA is a “karst system,” which means that the carbonate rocks of the aquifer system have been dissolved creating large dissolution channels in the limestone that allow for increased flow of water and produce characteristic landforms such as sinkholes and caves. Therefore, the UFA is highly productive with very high transmissivities in most places (meaning that water is able to enter, move through, and discharge from the UFA more readily and rapidly).

As a result, the UFA is quickly rechargeable with precipitation events, unlike other slow recharging aquifer systems like those in Texas that take hundreds of years to recharge.

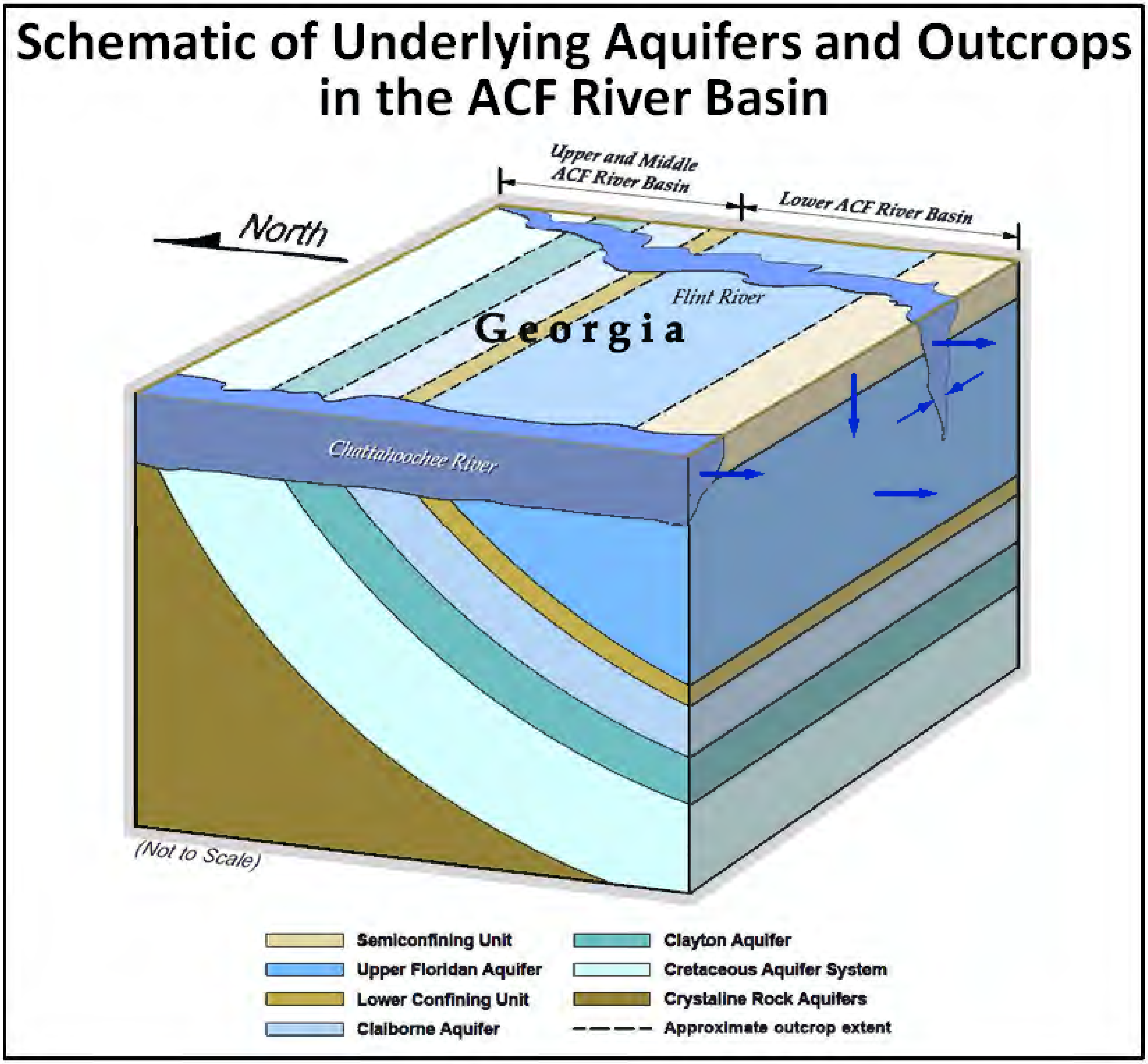
28. As a result of the aquifer's extremely high transmissivity, irrigation wells in the UFA can have substantial capacity. Well yields can range from several hundred to more than 10,000 gal/min (gallons per minute), depending on construction features, depth, and the location of the well. Wells that yield several thousand gal/min are uncommon and considered extremely high productivity wells in the United States. The highly productive nature of the UFA is the reason that most groundwater pumping in the ACF River Basin occurs from the UFA.

2. Piedmont Crystalline Aquifers

29. The Piedmont Crystalline Aquifers outcrop in the northern part of the ACF River Basin. There is very little pumping in the Crystalline Aquifers due to their low productivity.

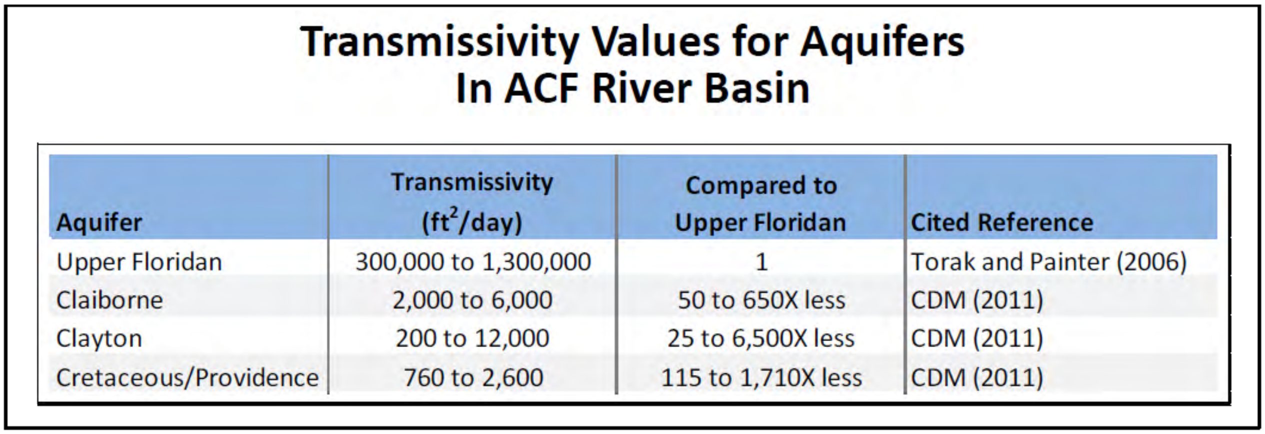
3. Claiborne, Clayton, and Providence/Cretaceous Aquifers

30. The deeper aquifers underlying the UFA in the Lower ACF River Basin are the Claiborne, Clayton, and Providence/Cretaceous Aquifers. These Aquifers reach the surface—or outcrop—to the north of the UFA in the Middle and Upper portions of the ACF River Basin, as shown on Panday Demo. 5 below. When it rains, water infiltrates into these aquifers in the outcrop areas and recharges (refills) them. Surface streams are incised into the Claiborne, Clayton, and Cretaceous Aquifers in their respective outcrop areas, where the aquifers contribute groundwater to streamflow (i.e., baseflow). But even in their outcrop areas, these aquifers have reduced interactions with streams due to their lower transmissivity as compared to the UFA. Where these aquifers underlie the UFA, they are separated by confining units (impervious and semi-pervious layers) and are not connected to the UFA or to the overlying rivers or streams.



Panday Demo. 5 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

31. The impact of pumping in the Claiborne, Clayton, and Cretaceous Aquifers on streamflow in the ACF River Basin is small and therefore has not been included in previous studies that focus on basin-wide streamflow impacts. As noted on Panday Demo. 6 below, these aquifers have much lower transmissivity than the UFA (up to 6,500 times less), with a correspondingly lower connectivity to rivers and streams that are incised in them. In addition, because these aquifers are less productive, there is significantly less groundwater pumping from them than from the UFA.



Transmissivity Values for Aquifers
In ACF River Basin

Aquifer	Transmissivity (ft^2/day)	Compared to Upper Floridan	Cited Reference
Upper Floridan	300,000 to 1,300,000	1	Torak and Painter (2006)
Claiborne	2,000 to 6,000	50 to 650X less	CDM (2011)
Clayton	200 to 12,000	25 to 6,500X less	CDM (2011)
Cretaceous/Providence	760 to 2,600	115 to 1,710X less	CDM (2011)

Panday Demo. 6 — Table of Transmissivity Values for Aquifers in the ACF River Basin (GX-0090, JX-076).

4. Lake Seminole

32. Groundwater pumping inside the Georgia portion of the Lower ACF River Basin does not affect groundwater/surface water interaction in Florida because Lake Seminole stabilizes groundwater levels in its vicinity. Lake Seminole is the reservoir created by the Jim Woodruff Lock and Dam (Woodruff Dam) at the state line between Florida and Georgia. Lake Seminole is generally maintained, as per the U.S. Army Corps of Engineers (USACE) operations, at a pool altitude of approximately 77 feet above Mean Sea Level (ft MSL), even during drought conditions and the groundwater pumping season. Lake Seminole is in direct contact with the UFA; therefore, it stabilizes the groundwater levels in the UFA in its vicinity. Drawdown from pumping in Georgia therefore does not extend further downstream of Lake Seminole and Woodruff Dam into Florida. I have observed this stabilizing effect in my own modeling efforts.

33. Other than noting that Lake Seminole stabilizes groundwater levels in its vicinity, I did not assess groundwater flow into the Florida portions of the UFA nor did I model the actual flow of the Apalachicola River from Lake Seminole into Florida. Water in the ACF River Basin flows through the federal reservoir system prior to entering Florida and I have not modeled these reservoir operations that control the flow. My impact-to-streamflow calculations reflect pumping-related changes to streamflow within Georgia only, and another expert, Dr. Philip Bedient, has analyzed the surface water flow system in the ACF River Basin which includes releases from Lake Seminole into Florida.

D. Numerical modeling of the impact of pumping from the UFA on streamflow in the ACF River Basin.

34. Numerical modeling is the best and most accurate way to calculate the impact of groundwater pumping on streamflow in the ACF River Basin. Groundwater modeling is a powerful tool that can be used to evaluate the effects of various past, present, or potential hydrological changes (e.g., temperature, precipitation, groundwater pumping, land-use, or streambed alterations) on the behavior of water levels and flows within the study area (i.e., domain). A numerical model can also isolate the impacts on streamflow from weather conditions and groundwater pumping at various locations and during various times. Indeed, it is the best tool available to quantify the relative influence of these factors on groundwater levels and streamflow.

35. Groundwater models fall into two general categories: i) steady-state models, which do not consider changes over time; and ii) transient models, which simulate changes over time. A steady-state model is useful to represent sustained conditions (i.e., a long dry spell), impacts of sustained changes, or an average condition (e.g., annual average). A transient model is required for simulating time-varying conditions (e.g., seasonal variations, long-term growth, or impacts of short-term changes).

36. For my modeling, I primarily used the most up-to-date MODFE transient model of the Lower ACF River Basin that was published by Jones and Torak (2006) (JX-018). This model was developed by USGS (the federal agency with expertise in assessing streamflow impacts from agricultural pumping) and Georgia EPD, specifically to assess the impact of groundwater pumping from the UFA in Georgia on streamflow in the ACF River Basin. This is the best available model for this purpose as noted also by Dr. Langseth in his expert report as well as his deposition testimony.[1] In order to analyze the impact of groundwater pumping on streamflow in the UFA, I input historical and current groundwater use and acreage estimates. I

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[1] Expert Report of D. Langseth (FX-795), 37 *("I selected the model developed by Jones and Torak (2006) (Jones and Torak MODFE model) as the best currently available simulation model to address this question")*; Dep. Tr. of D. Langseth, 678:2-9 *("Q. Do you agree that the Jones and Torak 2006 model is the best currently available simulation for the Upper Floridan aquifer in the ACF Basin? A. For the purpose of evaluating the interaction between — or the impact on the pumping the stream flow, I think it's the best currently available model.")*

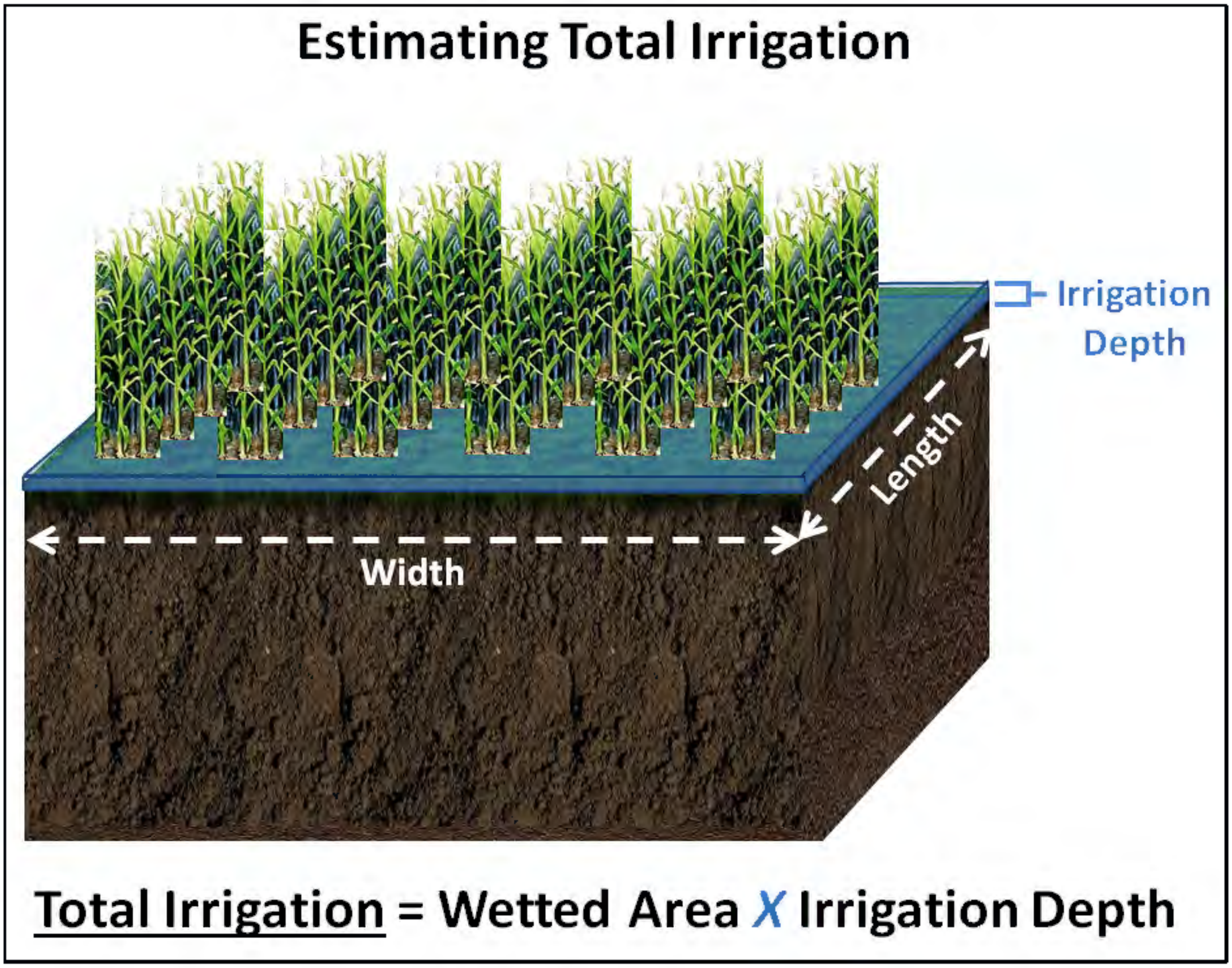
then used the model results to evaluate the impact on streamflow for my various modeling scenarios.

E. Estimating groundwater use.

37. Water use within the Lower ACF River Basin includes agricultural irrigation and municipal and industrial (M&I) uses. I estimated this groundwater use based on population trends and area of land irrigated in 1992, 2011, and 2013. I then developed modeling scenarios for these years, based on groundwater pumping that would occur under normal weather conditions and a scenario based on groundwater pumping I would expect during a drought. I used 1992 because it is my understanding that Florida seeks to cap Georgia's water use at levels that existed in 1992. I selected 2011 because it was a dry year with the highest irrigation pumping according to my calculations. I also used 2013 because I had updated acreage values for 2013 at the time that I ran my model simulations—also, 2013 had relatively normal hydrologic and precipitation conditions which resulted in normal agricultural irrigation pumping within the ACF River Basin. My modeling and analyses methodologies are detailed below.

1. Estimating Agricultural Groundwater Use

38. The best way to estimate agricultural irrigation pumping in the ACF River Basin is to estimate basin-wide irrigation depths and multiply those by total basin-wide acreages as illustrated below in Panday Demo. 7. Dr. Langseth and other Florida experts also determined this to be the best way to estimate irrigation pumping within the Basin.



Panday Demo. 7 — Estimating Total Irrigation.

39. The irrigation depth reflects the water demand by crops under a particular condition (dry, wet, or normal). The basin-wide irrigation depths are best computed by using the metering data available on a large portion of the fields in the Lower ACF River Basin in Georgia. Georgia EPD provided me with the metering data that it used to estimate basin-wide irrigation depths (JX-0143).[2] This data included meter readings from irrigation systems and corresponding acreage irrigated by the water flowing through each meter. In Panday Demo. 8 below, I present my computed basin-wide annual average irrigation depth for the years 2008, 2010, 2011, 2012, 2013, and 2014 and the values calculated by Georgia EPD. Because the values I calculated were so similar to those calculated by Georgia EPD, I used the Georgia EPD irrigation depths in my

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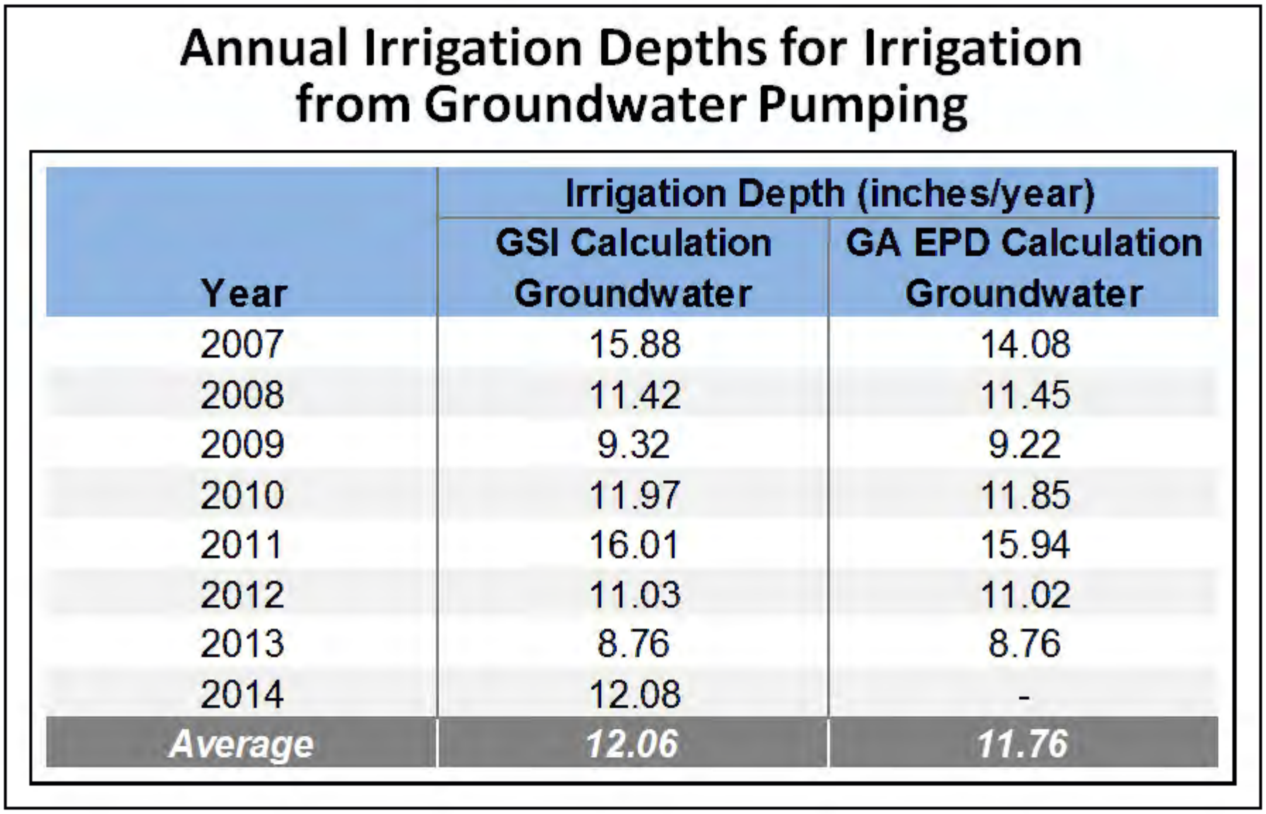
[2] *See* GX-0903; GX-0918 is a true and accurate copy of "2009_Water_Usage_GSWCC.xls"; GX-0925 is a true and accurate copy of "2012 Usage for EPD.xlsx"; GX-0929 is a true and accurate copy of "2013_Water_Usage_EPD.xlsx".

modeling effort. The highest irrigation depth was in 2011 and I used that to represent crop irrigation requirements for drought conditions. I used the average of the irrigation depths to represent crop irrigation requirements for normal weather conditions.



Annual Irrigation Depths for Irrigation from Groundwater Pumping

Year	Irrigation Depth (inches/year)	
	GSI Calculation Groundwater	GA EPD Calculation Groundwater
2007	15.88	14.08
2008	11.42	11.45
2009	9.32	9.22
2010	11.97	11.85
2011	16.01	15.94
2012	11.03	11.02
2013	8.76	8.76
2014	12.08	-
Average	*12.06*	*11.76*

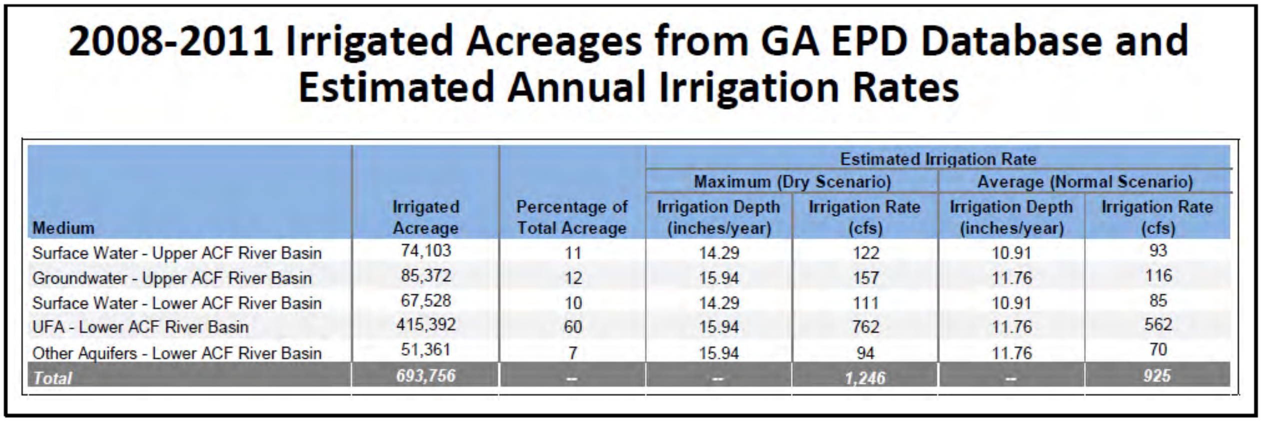
Panday Demo. 8 — Panday Expert Report (GX-0873), 20 May 2016, Table C-3.

40. The area being irrigated (i.e., wetted area) is the second piece of data needed to calculate total agricultural water use. I relied on various files from Georgia EPD to calculate total acres irrigated in the entire ACF River Basin; specifically from the UFA in Georgia within the MODFE domain. For my 2011 irrigated acreage, I relied on data collected by University of Georgia's National Environmentally Sound Production Agriculture Laboratory (NESPAL) as part of Georgia's State Water Plan. (JX-034) At the time of my analysis, this data was the most up-to-date verified data. I also analyzed irrigated acreage from 2013 provided by Georgia EPD, but those estimates were preliminary (GX-1259).

41. In addition, I wanted to be able to assess scenarios involving 1992 acreage, because Florida's complaint sought to cap *"Georgia's overall depletive water uses at the level then existing on January 3, 1992."* Since there is no observation-based data available for 1992

acreage, I estimated this acreage by using state-wide irrigation trends. Based on observed data from Dr. James Hook (2005) (GX-0080) through 2004, and permit data for the Lower ACF River Basin from Georgia EPD for 2004 through 2011, I found that 1992 had about 77% of 2011 irrigated acreage, so I uniformly reduced pumping to 77% of 2011 pumping values to estimate 1992 pumping.

42. In Panday Demo. 9 below, I show the number of acres irrigated by water source and location derived from the NESPAL database (JX-043). To calculate total annual irrigation rate, I multiplied the irrigated acreage by the annual irrigation depth.



2008-2011 Irrigated Acreages from GA EPD Database and Estimated Annual Irrigation Rates

Medium	Irrigated Acreage	Percentage of Total Acreage	Estimated Irrigation Rate			
			Maximum (Dry Scenario)		Average (Normal Scenario)	
			Irrigation Depth (inches/year)	Irrigation Rate (cfs)	Irrigation Depth (inches/year)	Irrigation Rate (cfs)
Surface Water - Upper ACF River Basin	74,103	11	14.29	122	10.91	93
Groundwater - Upper ACF River Basin	85,372	12	15.94	157	11.76	116
Surface Water - Lower ACF River Basin	67,528	10	14.29	111	10.91	85
UFA - Lower ACF River Basin	415,392	60	15.94	762	11.76	562
Other Aquifers - Lower ACF River Basin	51,361	7	15.94	94	11.76	70
Total	*693,756*	--	--	*1,246*	--	*925*

Panday Demo. 9 — Panday Expert Report (GX-0873), 20 May 2016, Revised Table C-8.

43. The process I just described calculates the annual average irrigation pumping rates for drought and normal conditions. However, the Jones & Torak model requires monthly pumping estimates to evaluate the timing of impact to streamflow from pumping. A study conducted by Dr. Hook provides the monthly irrigation patterns in southwest Georgia using metering data from 1999-2004. (JX-017) Dr. Hook reported three different distributions: maximum monthly irrigation, mean monthly irrigation for those years, and minimum monthly irrigation as shown on Panday Demo. 10 below. I used the maximum irrigation distribution for my "dry year" pattern and the mean of monthly irrigations for my "normal year" pattern.

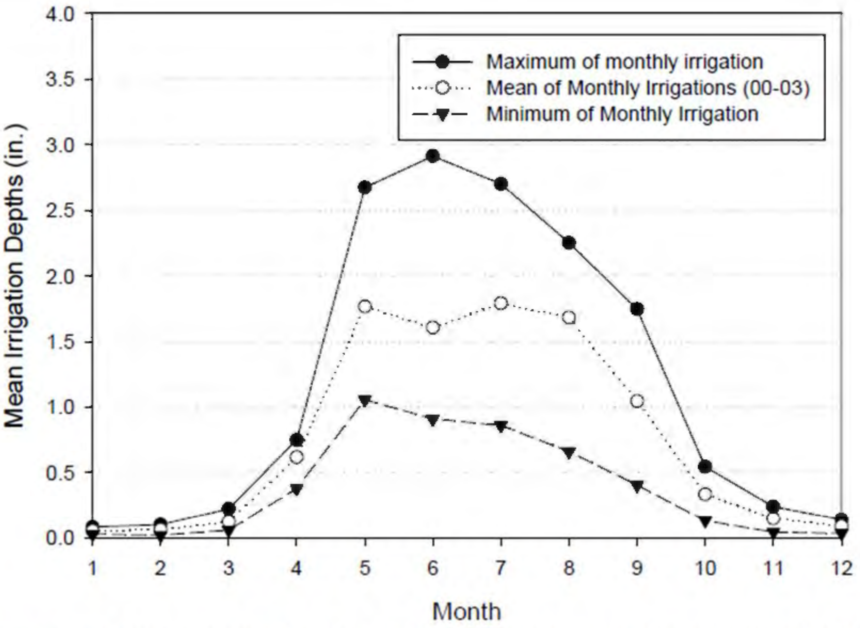


Figure 3-6. Mean monthly irrigation depths for fields in Southwest Georgia supplied by groundwater and maximum and minimum monthly amounts observed during 2000 to 2003.

Panday Demo. 10 — Hook (2005) (JX-017), Fig. 3-6 showing mean monthly irrigation depths for fields in Southwest Georgia supplied by groundwater and maximum and minimum monthly amounts observed during 2000 to 2003.

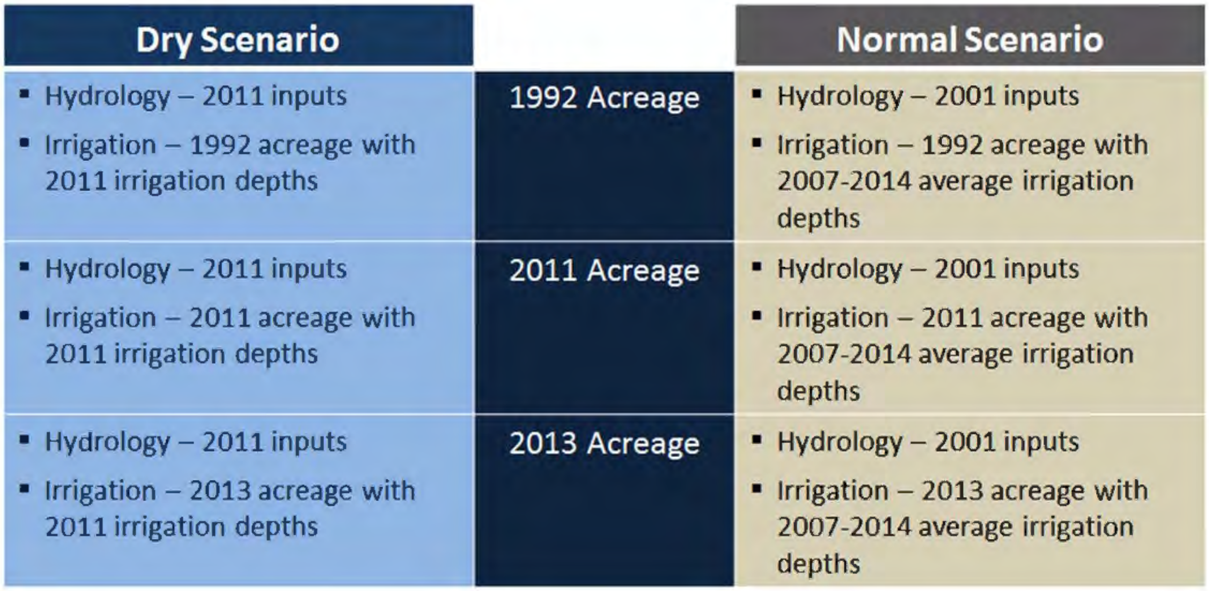
2. Estimating M&I Groundwater Use

44. I relied on M&I water use estimates provided by Georgia EPD for 2011 (GX-0903) and reported population trends to estimate M&I water use for 1992 and 2013 (GX-1214). I used a constant monthly withdrawal amount for M&I groundwater pumping as per the Jones and Torak (2006) simulations. M&I use does not vary significantly through the year and is a small component of the total withdrawals from the UFA therefore further evaluation of detailed monthly changes was not required for my simulations. I added the M&I pumping estimates to the agricultural pumping estimates from the UFA to give me the total pumping rates for my groundwater model simulations.

F. Modeling scenarios.

45. I used these water use estimates data to create six modeling scenarios: Dry Conditions for 1992, 2011, and 2013 acreages; and Normal Conditions for 1992, 2011, and 2013 acreages. I did not simulate a scenario for Wet Conditions since there is no reasonable shortage of water during wetter years. Also, because farmers irrigate less in wet years, the impact would

be even less than for the normal or dry scenarios. Dry/Normal conditions respectively, refer to dry/normal pumping demands and dry/normal hydrologic inputs. Panday Demo. 11 below shows how I have compiled irrigation pumping for my simulations.



Dry Scenario		Normal Scenario
▪ Hydrology – 2011 inputs ▪ Irrigation – 1992 acreage with 2011 irrigation depths	1992 Acreage	▪ Hydrology – 2001 inputs ▪ Irrigation – 1992 acreage with 2007-2014 average irrigation depths
▪ Hydrology – 2011 inputs ▪ Irrigation – 2011 acreage with 2011 irrigation depths	2011 Acreage	▪ Hydrology – 2001 inputs ▪ Irrigation – 2011 acreage with 2007-2014 average irrigation depths
▪ Hydrology – 2011 inputs ▪ Irrigation – 2013 acreage with 2011 irrigation depths	2013 Acreage	▪ Hydrology – 2001 inputs ▪ Irrigation – 2013 acreage with 2007-2014 average irrigation depths

Panday Demo. 11 — Description of Model Inputs for Dry and Normal Scenarios.

46. For my dry (i.e., drought) conditions pumping scenario, I selected irrigation depths from 2011 because that was the driest year with the largest estimated annual irrigation depths recorded. Therefore, my "dry scenario" likely overestimates the amount of actual groundwater pumping in a typical dry year. For my normal year pumping scenario, I used the average of the annual irrigation depths for 2007 through 2013. These years include extreme multi-year droughts, so using an average likely overstates the amount of groundwater pumping that would be expected in a typical normal year.

47. I also used two different sets of hydrologic inputs—Jones and Torak had a dataset for 2001 and Georgia EPD developed a dataset for 2011. Hydrology datasets contain information on monthly infiltration of precipitation, stream levels, and water levels at lateral boundaries and within the overburden. I selected the year 2011 to represent the dry scenario for hydrology because the year 2011 was a historical drought year with historically high annual irrigation demands. Thus, it was a reasonable choice for evaluation of dry (*i.e.*, extreme drought)

conditions. I selected the year 2001 to represent the normal scenario even though 2001 was dry in the Lower ACF River Basin and was the in the middle of a multi-year drought (1998-2002) according to Jones and Torak, (2006) (JX-018), p. 3. Therefore, 2001 is a conservative choice for evaluation of normal conditions. I used 2001 hydrologic inputs to represent normal weather conditions because this information was available from the MODFE datasets that were provided by Georgia EPD and USGS and was therefore convenient to use. However, as I demonstrate later, reduction in streamflow as a result of groundwater pumping is not impacted by the hydrologic inputs but only by the pumping quantities, location and timing.

48. To isolate the impact of pumping on streamflow in the Lower ACF River Basin, I ran model simulations with a certain scenario of groundwater pumping under specific hydrologic conditions and then re-ran the simulation under the same hydrologic conditions but without any groundwater pumping (i.e., zero pumping). By subtracting the total simulated groundwater entering streams (i.e., the baseflow) in the pumping scenario from that of the no-pumping scenario, I was able to isolate the relative change in streamflow caused by pumping. Hydrology inputs like weather influence the total amount of groundwater entering streams, but they do not affect the impact-to-streamflow computation. This is because their effect is cancelled out in the process of subtracting the results of a pumping scenario from that of a non-pumping scenario, with otherwise identical hydrologic inputs.

V. GROUNDWATER PUMPING FROM THE UFA IN GEORGIA HAS A MINIMAL IMPACT ON STREAMFLOW AT THE FLORIDA GEORGIA STATE LINE

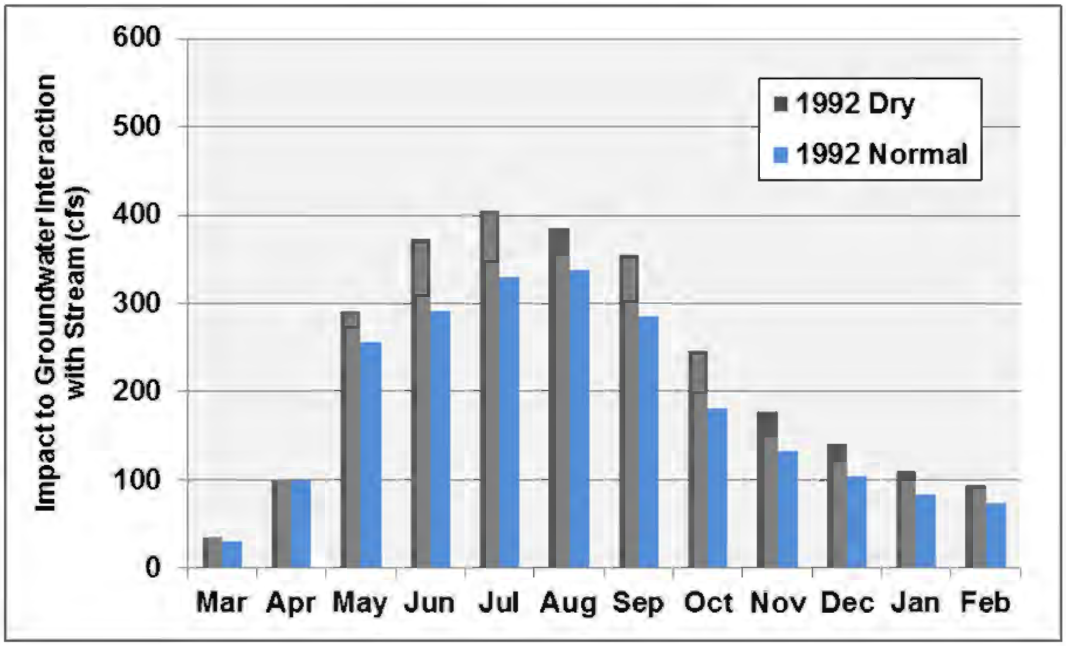
A. Results from my MODFE model simulations show that groundwater pumping in the UFA causes a small impact on streamflow into Florida.

49. I found that groundwater pumping from the UFA has a minimal impact on streamflow in the ACF River Basin into Florida. In other words, the amount of water flowing into the rivers and streams from the UFA within the ACF River Basin, is not materially impacted by agricultural irrigation pumping within Georgia when compared to even the ***minimum*** flows at the Chattahoochee Gage into Florida. I also compared the reduction in streamflow caused by groundwater pumping, to seasonal fluctuations as well as drought-related flow variations in the Apalachicola River. When placed in this context, the impact of groundwater pumping in the ACF River Basin is insignificant.

50. The results from my MODFE simulations for 1992, 2011, and 2013, respectively, are summarized in Panday Demos. 12 through 14 below (GX-0951). These results show that the amount of water flowing into the stream from the aquifer beneath the stream is not materially impacted by agricultural irrigation pumping by Georgia in the Lower ACF River Basin (with a reduction in baseflow of 511 and 428 cfs for Dry and Normal basin-wide pumping amounts, respectively using 2011 acreages).

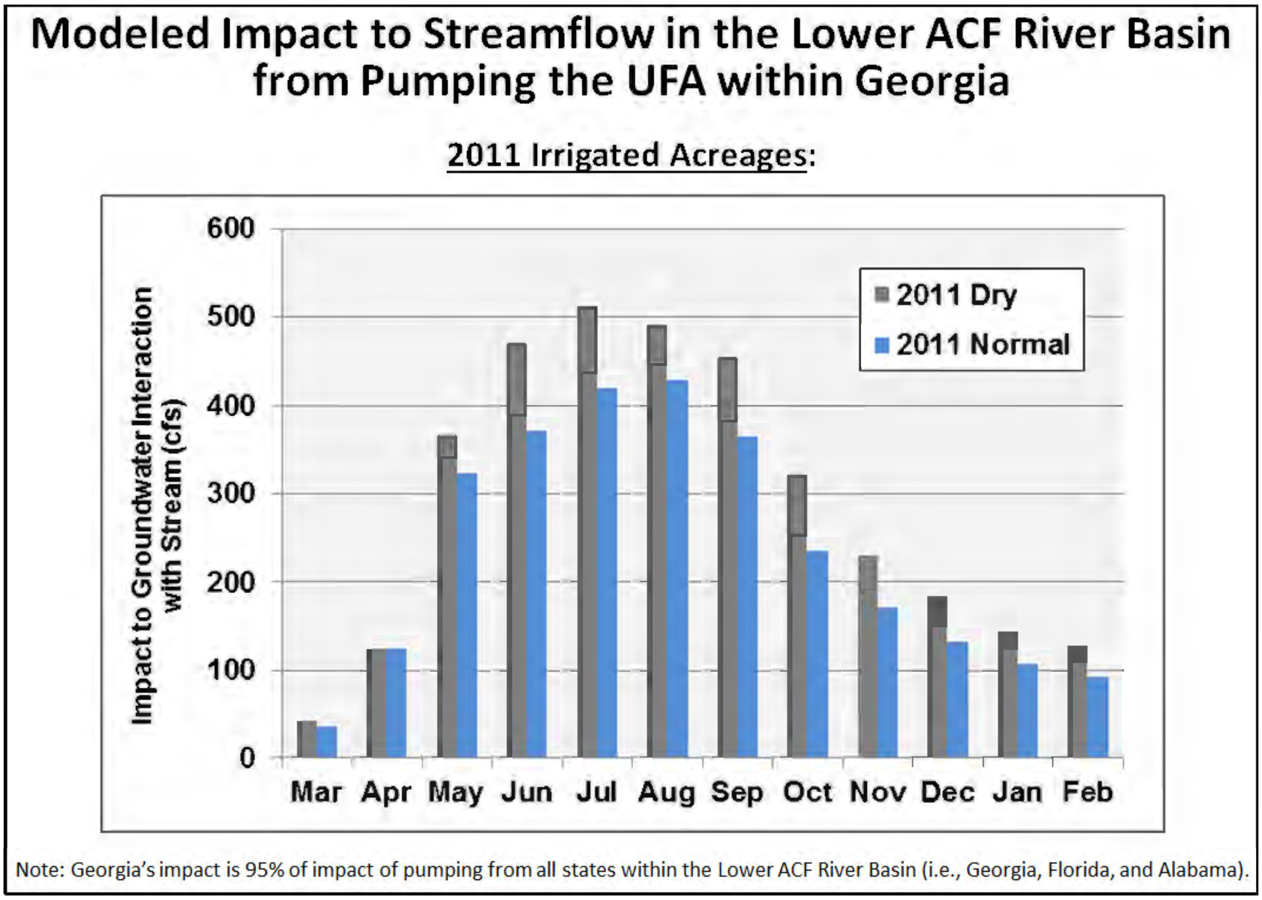
Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

1992 Irrigated Acreages:



Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

Panday Demo. 12 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.

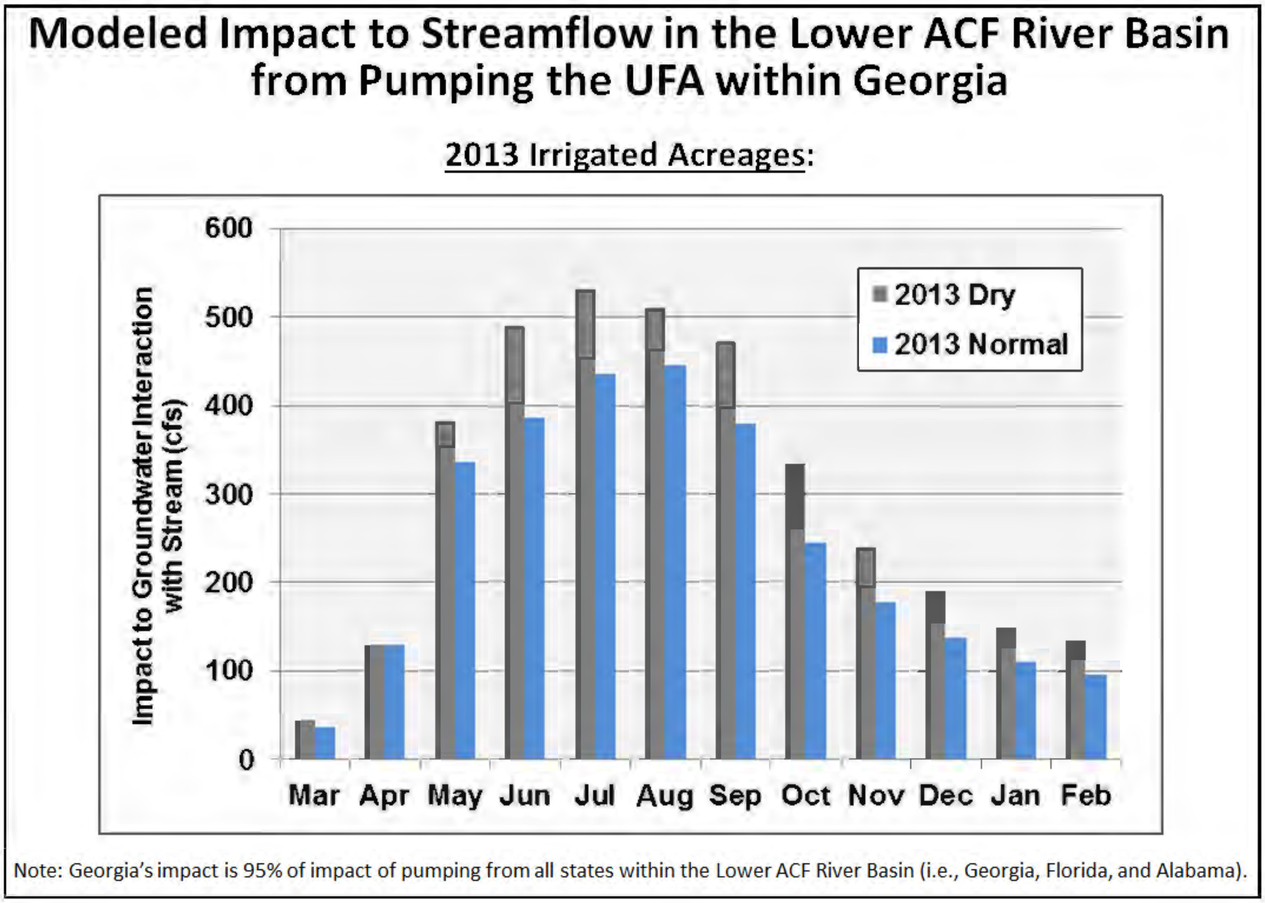


Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

2011 Irrigated Acreages:

Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

Panday Demo. 13 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.



Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

2013 Irrigated Acreages:

Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

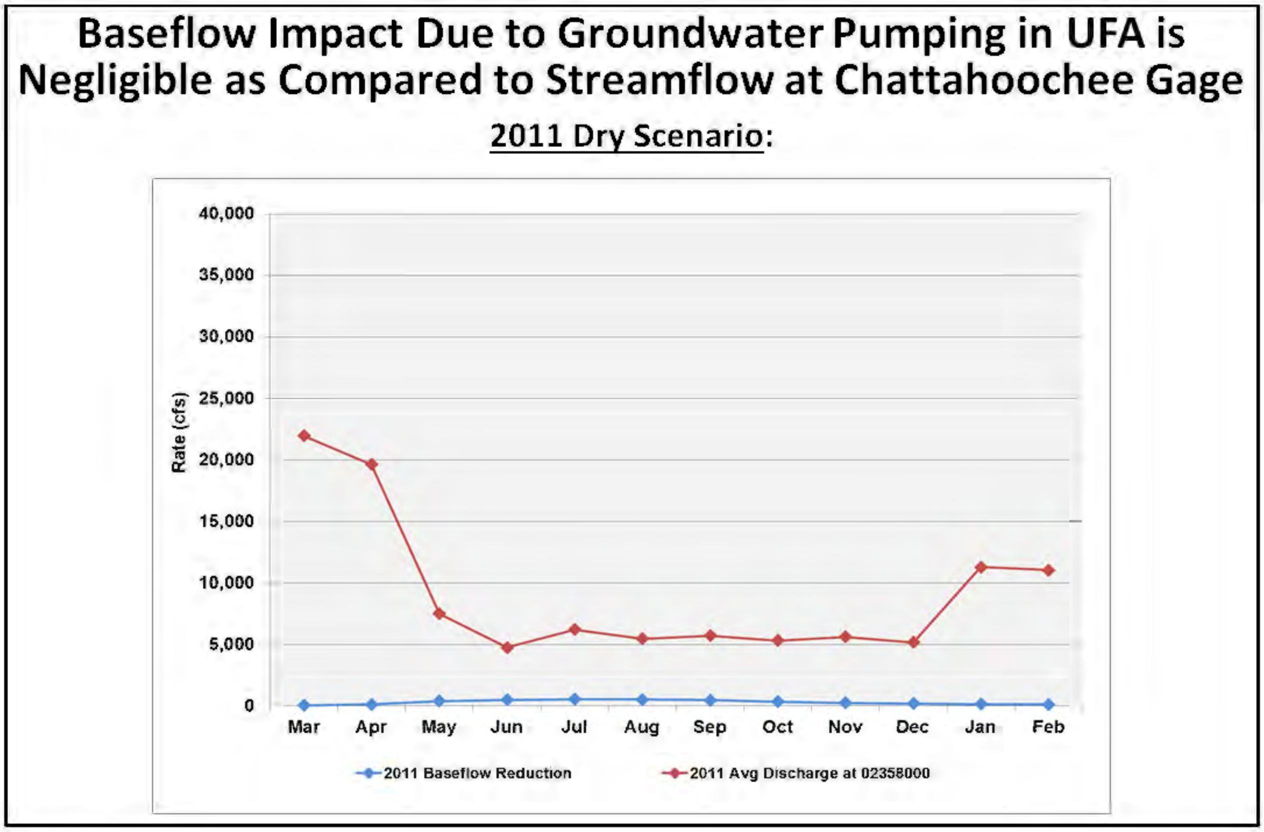
Panday Demo. 14 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.

51. Due to the small impact to streamflow caused by groundwater pumping from the UFA in Georgia, uncertainties or errors in estimates of agricultural irrigation pumping also have a small impact. For instance, I compute an impact to streamflow of 511 and 428 cfs for Dry and Normal basin-wide pumping amounts in peak months, respectively, using 2011 acreages. Thus, if the acreages were underestimated by 10% basin-wide, the resulting impact to streamflow would be an error of about 51 cfs for dry, and 43 cfs for normal irrigation depth requirements.

B. Streamflow reductions caused by groundwater pumping from the UFA in Georgia are minimal compared to streamflow into the Apalachicola River at the Chattahoochee Gage.

52. Even during the extreme drought year of 2011, the impact of groundwater pumping from the UFA was minimal compared to flow into Florida. Panday Demo. 15 below shows the actual monthly flows from Woodruff Dam into Florida in 2011 and simulated monthly impact to streamflow from pumping within the Lower ACF River Basin. During this extreme

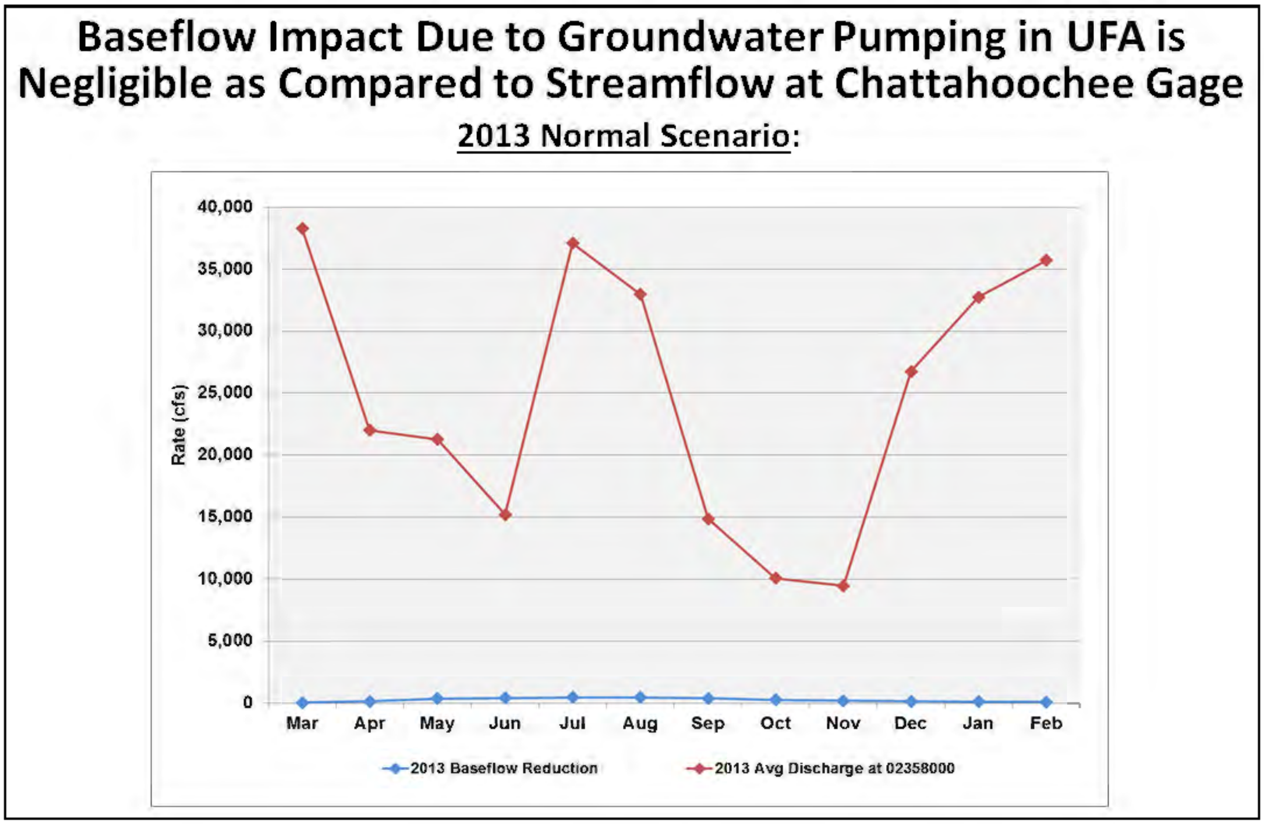
drought year, the maximum monthly average reduction in streamflow was 511 cfs as a result of groundwater pumping in the Georgia portion of the Lower ACF River Basin while minimum flows into Florida were almost 10 times larger at 5,000 cfs.



Panday Demo. 15 — Created from data in Panday Expert Report (GX-0873), 20 May 2016, Revised Fig. E-9. Flow data from Chattahoochee gage was obtained from the USGS (JX-128).

53. The relative impact of groundwater pumping in the Lower ACF River Basin in Georgia on total streamflow to Florida is even less significant during normal precipitation years. Panday Demo. 16 below shows actual monthly average flows at the Chattahoochee Gage in 2013 along with the estimated impact to streamflow (i.e., baseflow reduction) caused by pumping for the 2013 Normal Scenario. In 2013, a year reflecting relatively normal levels of precipitation and streamflow, groundwater pumping in the Georgia portion of the Lower ACF River Basin caused a maximum monthly impact of 446 cfs in August. The minimum monthly flow at the Chattahoochee Gage during 2013 was just below 10,000 cfs in November (about 22.7 times higher). Thus, the impact of UFA pumping within Georgia on streamflow in the basin is about

4.5% of the minimum flow at the Chattahoochee Gage into Florida for normal precipitation and weather conditions.

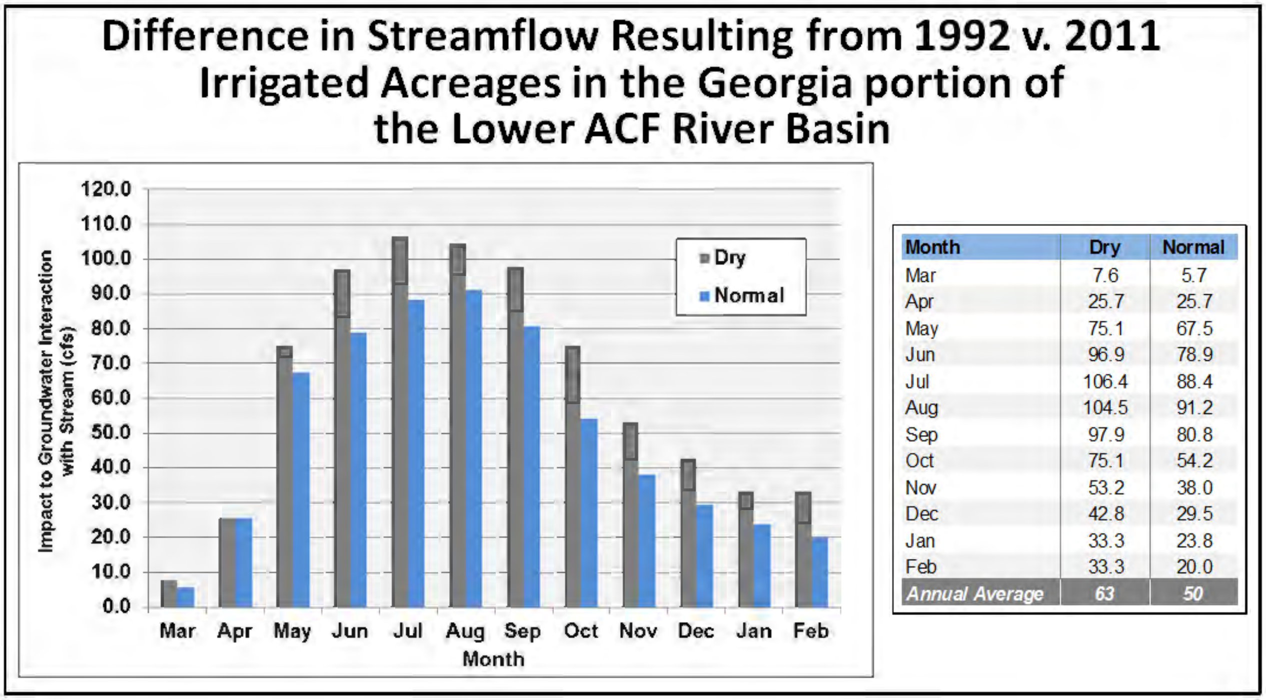


Panday Demo. 16 — Created using data from Panday Expert Report (GX-0873), 20 May 2016, Revised Figure E-9. Flow data from Chattahoochee gage was obtained from the USGS (JX-128).

C. My modeling shows only small changes in impact to streamflow from groundwater pumping since 1992.

54. Groundwater pumping in the Lower ACF River Basin has increased since 1992, but this increase has had a negligible incremental impact on streamflow. Panday Demo. 17 below shows the difference between the impact of current (i.e., 2011) and 1992 levels of groundwater pumping on streamflow under dry and normal pumping conditions. The maximum difference between monthly impact to streamflow under 2011 and 1992 irrigation levels is only 106.4 cfs. This value is relatively small because the irrigated acreage has not increased substantially since 1992—as I noted earlier, the estimated irrigated acreages in 1992 were 77% of 2011 irrigated acreages. Furthermore, this reduction of 106.4 cfs between 1992 and current

conditions is negligible (50 times smaller) in comparison to even the minimum flow of 5,000 cfs into Florida.



Difference in Streamflow Resulting from 1992 v. 2011 Irrigated Acreages in the Georgia portion of the Lower ACF River Basin

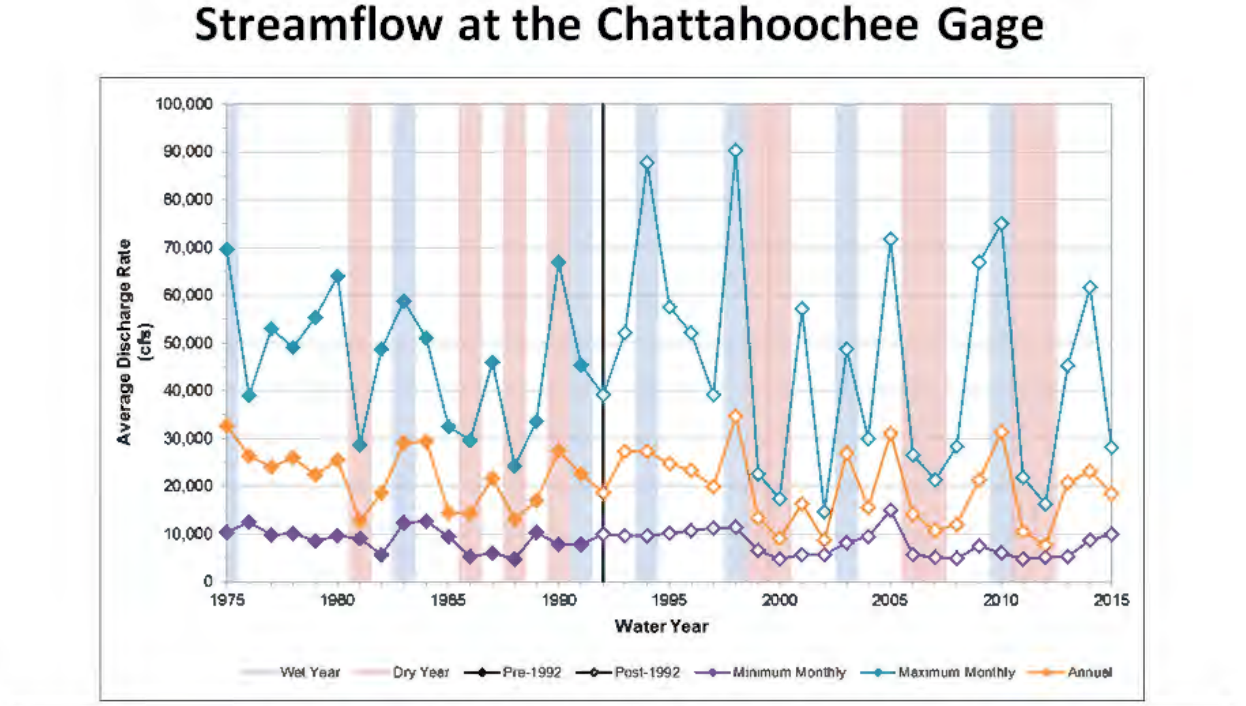
Month	Dry	Normal
Mar	7.6	5.7
Apr	25.7	25.7
May	75.1	67.5
Jun	96.9	78.9
Jul	106.4	88.4
Aug	104.5	91.2
Sep	97.9	80.8
Oct	75.1	54.2
Nov	53.2	38.0
Dec	42.8	29.5
Jan	33.3	23.8
Feb	33.3	20.0
Annual Average	*63*	*50*

Panday Demo. 17 — Panday Expert Report (GX-0873), 20 May 2016, Fig. E-4.

55. My estimates may even overstate the difference between 1992 and current levels of irrigation. I estimated that irrigated acreage in 1992 was about 77% of the irrigated acreage in 2011. But Florida's own consumptive use expert, Dr. Flewelling, found that Georgia's agricultural water consumption in 1992 was about 87% of the total irrigation amounts from recent dry years. (Expert report of S. Flewelling, 39). If I were to use Dr. Flewelling's ratio of wetted acreage to estimate irrigation in 1992, the difference in impact to streamflow would be even smaller.

D. Weather has a greater impact on streamflow in the ACF River Basin than Georgia's groundwater pumping.

56. Streamflow reductions caused by groundwater pumping from the UFA are minimal compared to natural fluctuations caused by seasons or long-term (wet/dry) weather patterns. Panday Demo. 18 below summarizes the streamflow patterns at the Chattahoochee Gage from 1975 to present.



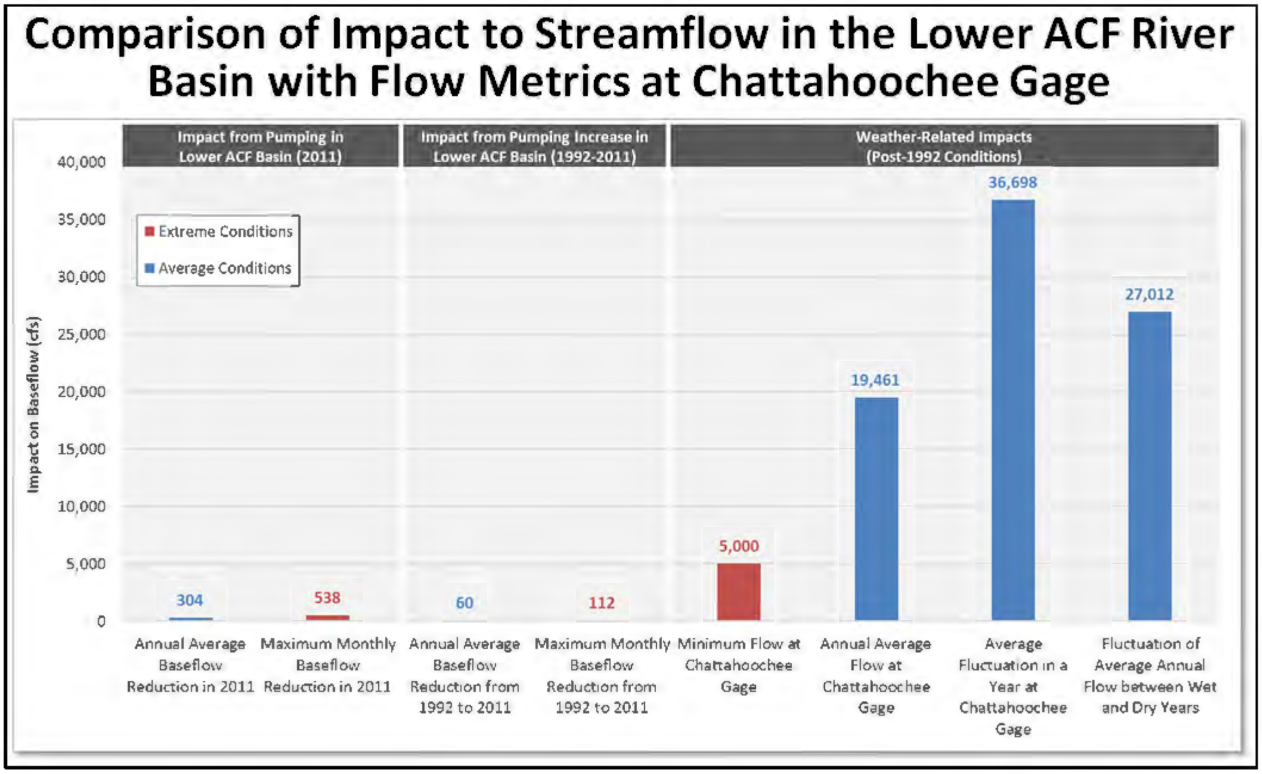
Time Period	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Average Discharge Rate (cfs)												
Minimum Monthly	4,750	4,781	7,885	5,573	9,476	7,810	10,423	9,980	12,635	15,087	8,968	7,986
Maximum Monthly	24,162	14,771	33,539	25,569	48,736	42,258	55,477	58,641	69,543	90,332	46,812	44,684
Annual	12,661	7,605	17,041	13,085	22,697	19,295	26,452	25,340	32,718	34,617	22,231	19,461

Panday Demo. 18 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-4. Flow data from Chattahoochee gage was obtained from the USGS (JX-128).

57. I have compared the annual streamflow fluctuations at the Chattahoochee Gage shown in Panday Demo. 18 above, to the monthly impact of groundwater pumping on streamflow from my modeling results. To have consistency in the time scale of my comparisons, I have compared the observed fluctuations within a year to the monthly impacts of pumping within a year. The annual streamflow fluctuation (difference between minimum monthly and maximum monthly flows into Florida for each year) for post-1992 conditions is as high as 75,561 cfs; averages 36,698 cfs; and is as low as 9,990 cfs. Thus, even the lowest annual fluctuation in the monthly average flow of almost 10,000 cfs, overwhelms the maximum monthly impact of 511 cfs from groundwater pumping in Georgia in 2011, an extreme drought year. In other words, the minimum fluctuation of streamflow within a year is almost 20 times larger than the maximum impact of UFA pumping within Georgia. The average annual

fluctuation of 36,698 cfs is over 82 times larger than the average impact (446 cfs in 2013, a normal year) of UFA pumping within Georgia. Thus, the natural seasonal variation in streamflow over a year, overwhelms any impact from groundwater pumping.

58. I have also evaluated the impact of dry versus wet weather periods on streamflow at the Chattahoochee Gage. As noted in Panday Demo. 18 above, the annual average streamflow at the Chattahoochee Gage can be as low as 7,605 cfs during a dry year and as high as 34,617 cfs during a wet year, indicating a fluctuation of 27,012 cfs between extreme dry and wet years for post-1992 conditions. If I consider the 25th percentile and 75th percentile statistics for annual flow to represent moderately dry and moderately wet years respectively, the fluctuation is over 12,000 cfs. In comparison, the annual average streamflow reduction caused by all pumping in Georgia is 304 cfs; indicating that the streamflow impacts on flow to Florida, of all UFA pumping in Georgia for a year, are negligible compared to the impacts imposed by dry or wet weather conditions for any year.



Panday Demo. 19 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 3-4. Flow data was obtained from the USGS (JX-128).

59. Panday Demo. 19 above summarizes the streamflow impacts from groundwater pumping in the Lower ACF River Basin, alongside some of the flow metrics discussed above, for flow into Florida measured at the Chattahoochee Gage. The impacts of pumping on streamflow reduction are significantly smaller than the seasonal or weather related impacts.

60. I also evaluated precipitation within the ACF River Basin. Panday Demo. 20 below shows the precipitation record at select National Oceanic and Atmospheric Administration (NOAA) stations across the ACF River Basin and indicates that there is a decline in overall precipitation from pre-1992 to post-1992 conditions.[3] The precipitation record also indicates more frequent, longer duration, back-to-back droughts for the post-1992 period over the ACF River Basin.

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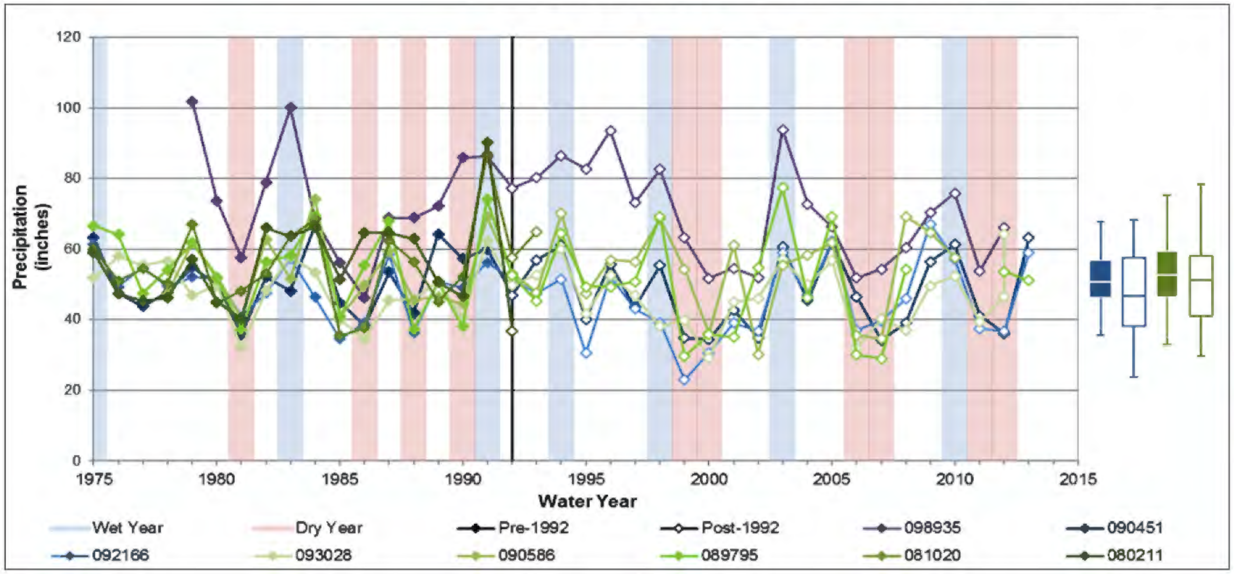
[3] Evaluating this for post-1998 conditions, (like my analysis of groundwater levels later in my testimony), would indicate an even larger decline, as the period from 1992 through 1998 was relatively wet, thus raising the post-1992 average.

Precipitation at Select NOAA Stations within the ACF River Basin



Summary Statistics

NOAA Station ID	Minimum Pre-1992	Minimum Post-1992	25th Percentile Pre-1992	25th Percentile Post-1992	Median Pre-1992	Median Post-1992	75th Percentile Pre-1992	75th Percentile Post-1992	Maximum Pre-1992	Maximum Post-1992	Average Pre-1992	Average Post-1992
Precipitation (inches)												
098935	46.1	51.7	68.6	54.5	72.1	70.3	85.9	80.2	101.7	93.8	74.2	69.6
Upper ACF River Basin	***34.6***	***23.0***	***45.2***	***37.4***	***49.6***	***45.7***	***55.9***	***56.5***	***66.6***	***67.1***	***50.1***	***46.5***
090451	35.8	34.2	44.8	39.3	49.8	46.0	57.3	56.8	66.6	63.2	51.1	47.8
092166	34.6	23.0	46.3	37.1	49.4	44.5	54.7	52.1	61.3	67.1	49.1	45.1
Lower ACF River Basin	***32.1***	***29.0***	***45.6***	***40.1***	***51.6***	***50.3***	***58.5***	***57.0***	***74.2***	***77.4***	***52.2***	***49.9***
093028	32.1	29.1	45.6	40.0	49.9	46.6	55.4	52.5	62.2	64.1	48.8	46.6
090586	40.4	30.2	45.8	47.5	50.6	56.5	61.3	61.5	74.2	70.0	53.3	53.6
089795	37.3	29.0	47.4	40.5	55.5	50.7	64.1	54.4	74.0	77.4	54.8	49.8
081020	35.5	–	48.1	--	53.0	–	62.3	–	86.9	--	55.1	–
080211	40.2	–	46.6	--	57.0	–	64.6	–	90.2	--	56.9	–
Upper and Lower ACF Basin	***32.1***	***23.0***	***45.5***	***39.1***	***50.9***	***48.5***	***57.7***	***56.9***	***74.2***	***77.4***	***51.4***	***48.4***

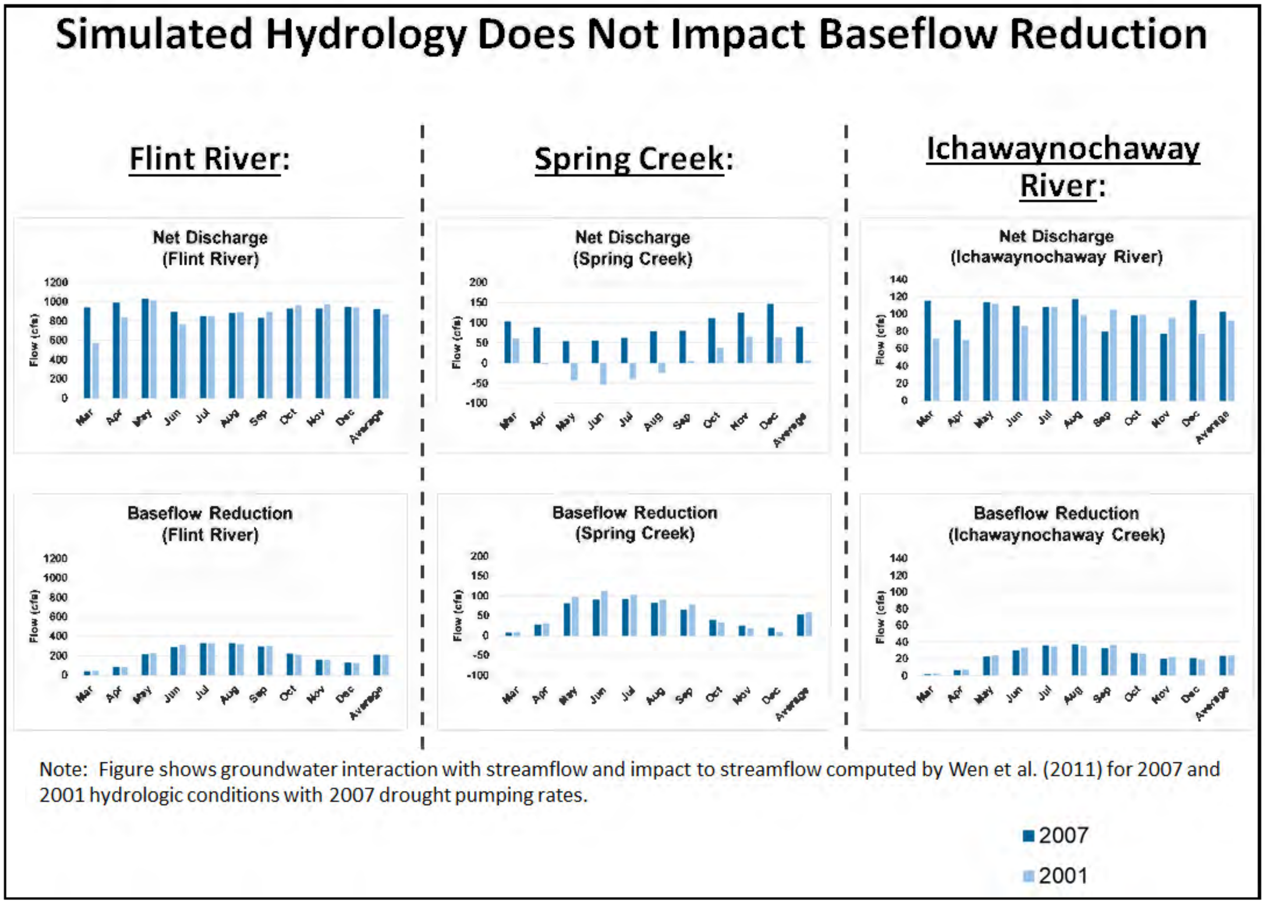
Panday Demo. 20 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure C-2. Data obtained from GA-1156, NOAA.

E. Hydrologic inputs (e.g., weather) control streamflow but do not affect the impact to streamflow from groundwater pumping.

61. In contrast to total streamflow which is strongly related to weather, the amount that groundwater pumping reduces streamflow is ***not*** dependent on the weather or the absolute streamflow value itself. For example, when my modeling shows reduction of 511 cfs as the impact to streamflow in July from groundwater pumping under dry conditions with 2011 acreage, the 511 cfs value is accurate no matter the weather. For example, if dry weather with no pumping would result in 2,000 cfs of groundwater contribution to streamflow in July, then pumping consistent with my 2011 Dry Pumping scenario would still result in 511 cfs reduction and the total groundwater flowing into streams for July would be 1,489 cfs (2,000 cfs - 511 cfs). If the weather was much wetter with 5,000 cfs of groundwater discharge into streams during July without pumping, pumping consistent with my 2011 Dry Scenario would still result in the ***same reduction*** of 511 cfs in June, resulting in a total contribution of groundwater to streams of 4,489 cfs (5,000 cfs - 511 cfs).

62.

63. Thus, the pumping related impact to streamflow is not affected by the total contribution of groundwater to streamflow. This was noted in the MODFE model of the Lower ACF River Basin by Wen et al. That study found that net streamflow from groundwater was sensitive to modeled hydrological conditions (the wetter the period, higher the total groundwater contribution to baseflow), while the reduction in streamflow caused by pumping correlated with the pumping rates (higher the pumping, higher the reduction in streamflow). This shows that streamflow reductions resulting from groundwater pumping can be reliably calculated from pumping alone—regardless of hydrology inputs. Panday Demo. 21 below shows the results from Wen et al. which illustrates this phenomenon.



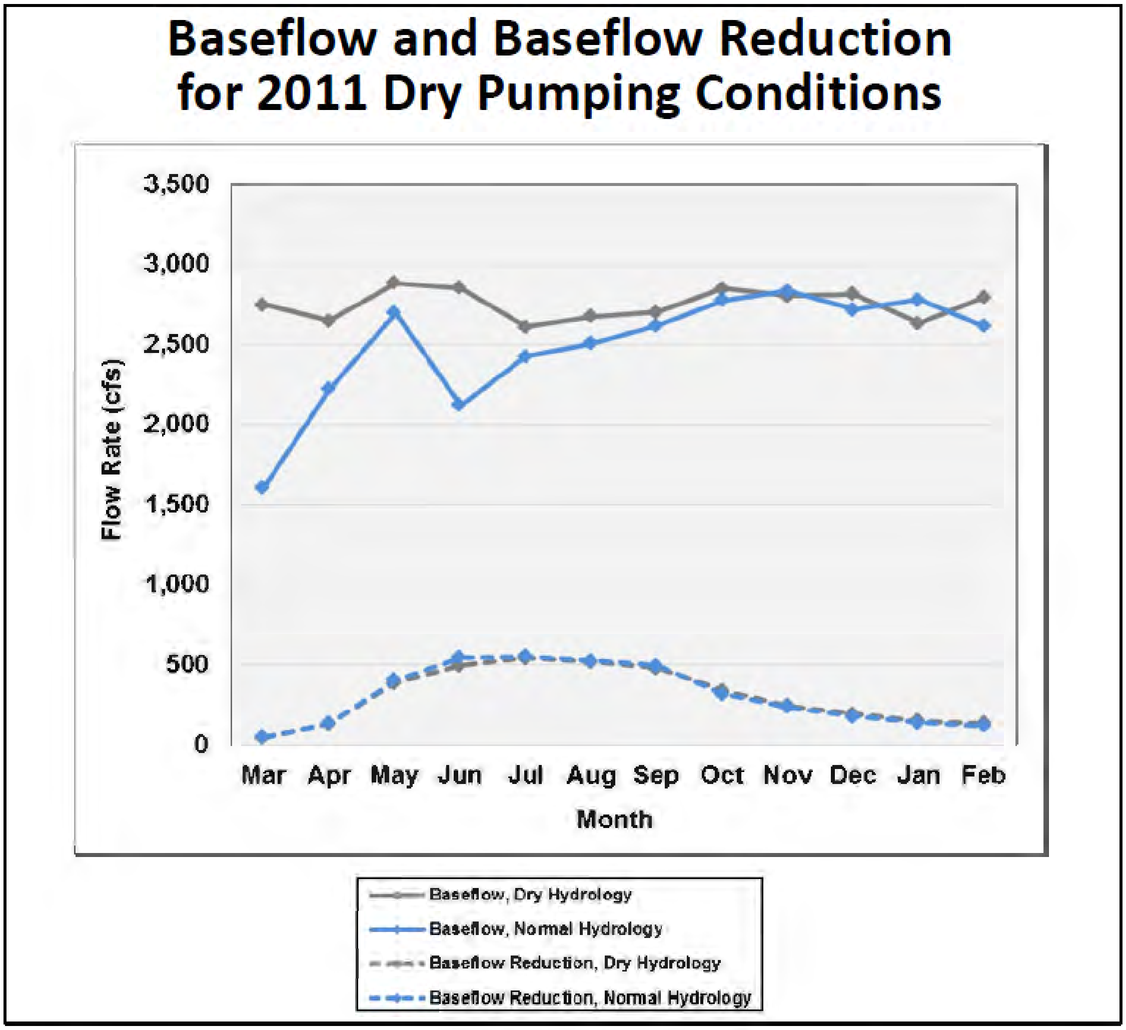
Note: Figure shows groundwater interaction with streamflow and impact to streamflow computed by Wen et al. (2011) for 2007 and 2001 hydrologic conditions with 2007 drought pumping rates.

Panday Demo. 21 —Panday Expert Report (GX-0873), 20 May 2016, Fig. 4-6.

64. Wen et al. used the same pumping patterns and pumping inputs (of 2007 conditions), but applied two different hydrology inputs (of 2001 and 2007 conditions) in baseflow reduction simulations using MODFE. The top row in Panday Demo. 21 above shows net discharge or the total modeled groundwater contribution to streamflow (i.e., baseflow). Negative values indicate that the river was providing water to the aquifer. For example, in Spring Creek the net discharge for 2001 and 2007 are quite different showing opposite (positive versus negative) flow conditions between May and August. The second row of charts in Panday Demo. 21 above shows the reduction to streamflow (i.e., baseflow reduction) caused by pumping. Even though the total baseflow values for 2001 and 2007 are quite different, the reductions to streamflow from pumping are about the same. The same behavior can be seen in the other panels as well. This shows that pumping—not hydrologic inputs—influence the modeled impact to streamflow.

65. Studies of the UFA in the Lower ACF River Basin have determined that the system generally responds linearly to changes in pumping. In other words, if the pumping rate is doubled, the reduction in groundwater entering the streams is generally doubled or if the pumping rate is halved, the reduction of groundwater entering the streams is halved. This occurs regardless of the simulated hydrologic inputs. Florida's groundwater expert Dr. Langseth did not model ***any*** hydrology because he assumed that the impact to streamflow from pumping changed linearly in response to changes in pumping—regardless of other hydrologic factors. I agree with this assumption so long as pumping distributions and timing remain unchanged.

66. Florida's experts in their direct testimony have challenged my results by focusing on total modeled contribution of streamflow from groundwater. But total modeled contribution of streamflow from groundwater is driven by hydrologic model inputs (like weather) and not groundwater pumping. Although this has been proven many times in the literature, I recently conducted an additional simulation to show that my results are consistent whether I use normal hydrology (2001 inputs) or dry hydrology (2011 inputs). I ran my "dry" pumping scenario for 2011 acreages using both normal and dry hydrology. Panday Demo. 22 below shows a comparison of the results of these two scenarios.



Panday Demo. 22 — Baseflow and Baseflow Reduction for 2011 Dry Pumping Conditions

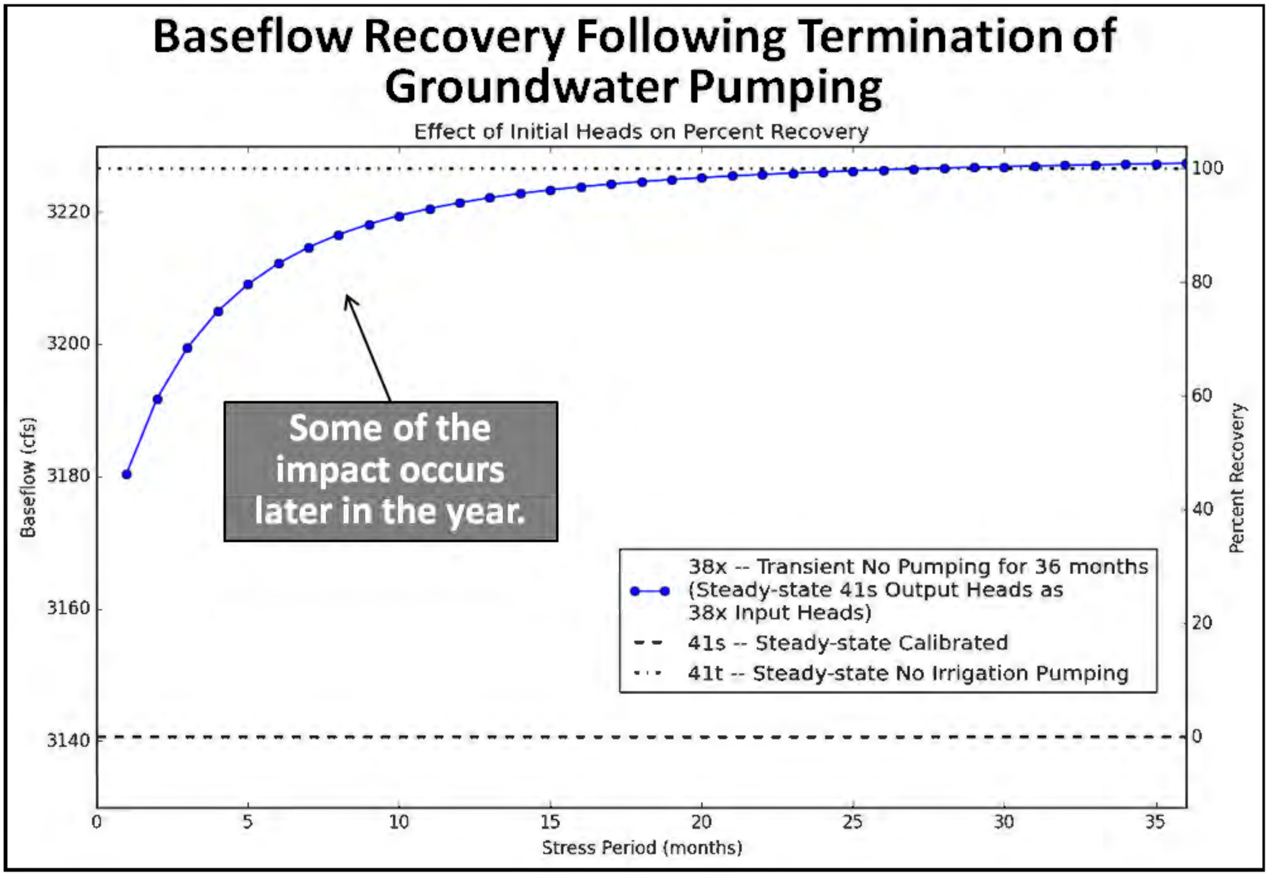
67. The results shown in Panday Demo. 22 indicate that even though the baseflow is different for the two scenarios (solid line) as a result of the different hydrology inputs, the baseflow reduction is the same (dashed line) because the pumping was the same for the two simulations. The objective of my evaluations was to investigate the impact of pumping and not to predict the baseflow. Thus, the streamflow reductions computed by this model are reliable even if total modeled baseflow in any scenario is not representative of a simulated year. This is why the model is such a powerful tool—the computed impacts to streamflow from pumping can be used to predict the impacts even when actual future weather conditions (and associated actual baseflow) are unknown.

F. Because of the time-lag effect, some reduction to streamflow occurs in wetter winter months.

68. The impact of groundwater pumping changes on streamflow is not immediate (referred to as a "time-lag" effect) and this delayed impact is spread over many months. As a result, some of the streamflow reduction from peak agricultural groundwater pumping in the dry seasons occurs during the wetter season, when streamflow is higher. Conversely, shutting off pumping only during the peak irrigation month will not realize the associated streamflow gains right away. I analyzed this time-lag effect in two ways as further discussed below.

69. First, my simulations over an annual cycle show that there is an approximately one month time-lag between peak agricultural pumping and peak streamflow reduction. Other studies have found similar results.

70. Second, I performed an evaluation of long-term time-lag. Torak and McDowell (1996) found that steady-state pumping impact to streamflow takes 100 to 1,000 days to be almost fully (97%) realized at the rivers. Thus, the impact of peak agricultural pumping continues into the wetter season when river flows are higher. Using the same technique described by Torak and McDowell (1996) but with the updated Jones and Torak MODFE model, I shut off all pumping and analyzed how long it took for streamflows to return to non-pumping levels. I found that after shutting off groundwater pumping, it took approximately 5 months for streamflow to return to 80% of its non-pumping conditions, and 26 months to be fully restored, as shown on Panday Demo. 23 below.



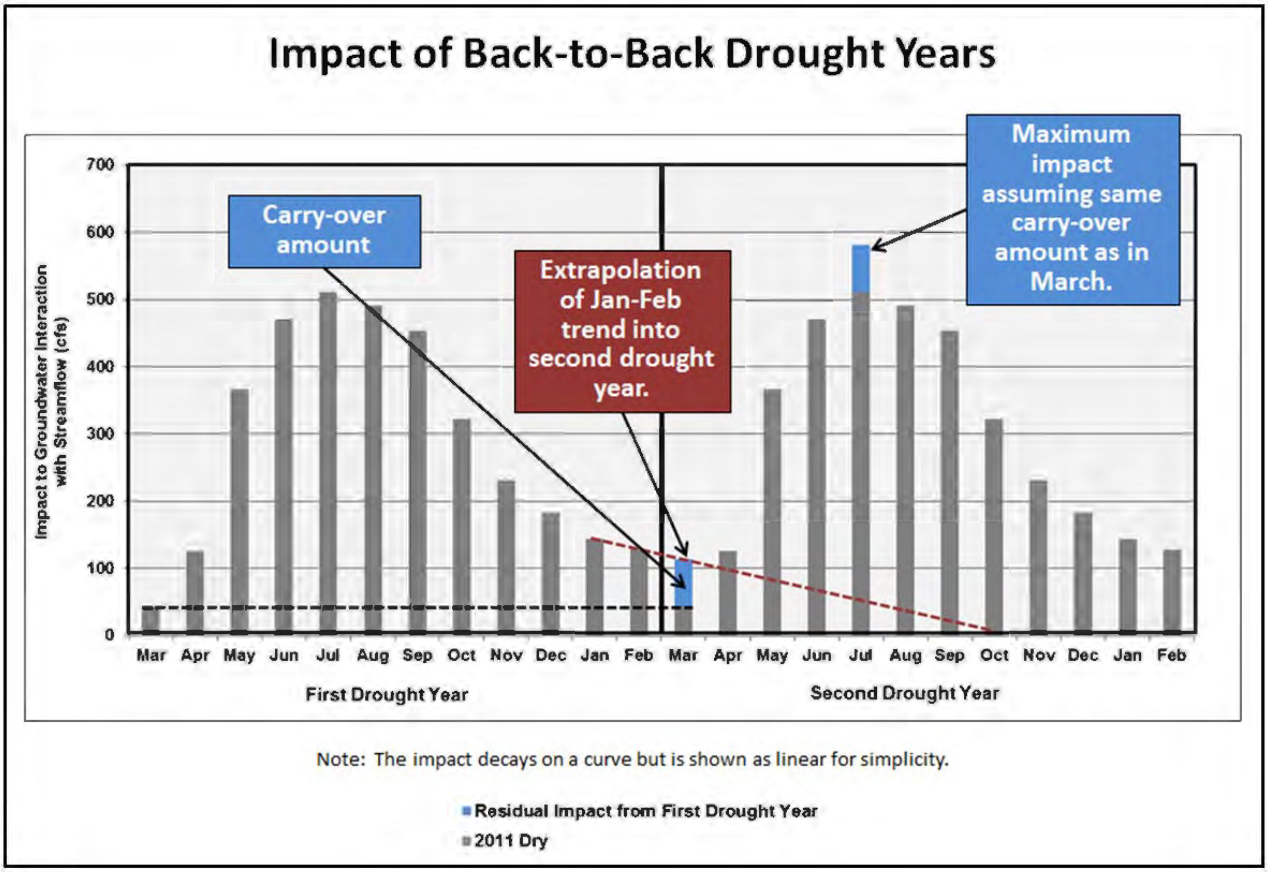
Panday Demo. 23 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 5-7.

71. Therefore, Panday Demo. 23 above shows that 20% of the impact of groundwater pumping has not occurred even after 5 months of shutting off groundwater pumping. The impact of peak agricultural irrigation pumping during the growing season is spread out into the wetter season; and even if Georgia decreases (or completely ceases) agricultural irrigation pumping during the growing season, the increase to streamflow will not be fully realized right away. Dr. Sunding's testimony is flawed because he assumes that gains from shutting off pumping during a peak irrigation month are fully realized right away. Instead, as seen in Panday Demo. 23 above, only about 50% of the full potential impact to streamflow would be felt at the end of the month for which pumping was shut-off.

G. Groundwater pumping in the Lower ACF River Basin has minimal "carry-over" impact on streamflow in the following year, even during back-to-back drought years.

72. Because time-lag can cause a carry-over effect, I also analyzed the impact of pumping from one year on streamflow the following year under back-to-back drought

conditions. To determine the carry-over impact, I extrapolated the impact to streamflow at the end of the 2011 dry transient simulation into the next year. During the simulation of 2011, the impact on streamflow from pumping in all three states grew through the summer to 538 cfs in July and then eventually decreased to 135 cfs at the end of the simulated model cycle in February of the following year. Extrapolating the declining trend, I estimate that the impact from groundwater pumping in March of the second drought cycle would be 119 cfs. This is shown in Panday Demo. 24 below. Therefore, when compared to the first drought year reduction of 46 cfs in March, an additional 73 cfs in reduction to streamflow gets carried over into the next year. This "carry-over" effect further diminishes with time; therefore, the long-term impact of groundwater pumping on streamflow during back-to-back drought years is relatively minimal.



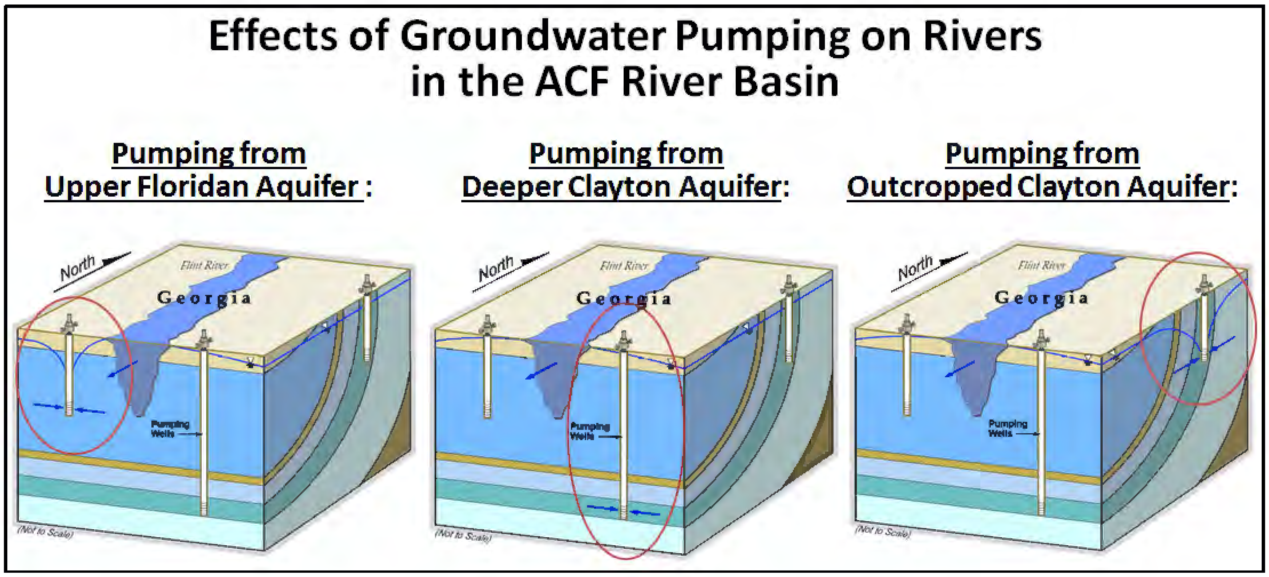
Panday Demo. 24 — Created using data from
Panday Expert Report (GX-0873), 20 May 2016, Fig. E-3.

H. Pumping from aquifers other than the UFA has a negligible impact on streamflow.

73. Prior studies that evaluated the basin-wide impact of groundwater pumping on streamflow in the ACF River Basin focused only on the UFA because the transmissivity of other aquifers is lower than the UFA's and, consequently, there is less of a connection to streams. Also, there is considerably less pumping in the other aquifers within the ACF River Basin compared to pumping in the UFA. I have evaluated the possible impact of all groundwater pumping from non-UFA aquifers and I agree that this impact is negligible (a peak monthly impact of around 21 cfs).

1. Impact of Groundwater Pumping from non-UFA Aquifers in the ACF River Basin

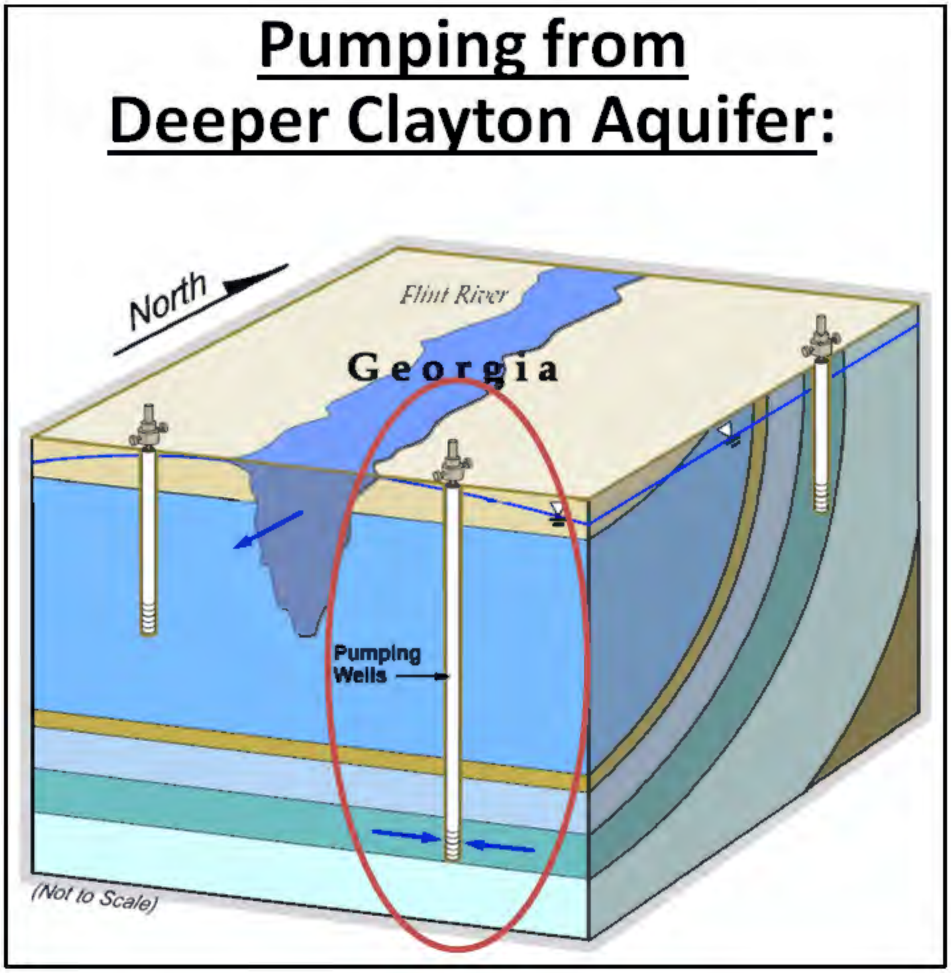
74. In the Lower ACF River Basin where the UFA exists, the Claiborne, Clayton, and Cretaceous Aquifers underlie the UFA in a stratified manner. Because they are separated from the surface by confining units and the UFA, they do not have a direct connection with streams and rivers of the ACF River Basin. Where these aquifers are at the surface (in their outcrop areas further to the north where the UFA is absent), they are incised by the overlying rivers and streams but the connectivity is lower as a result of their significantly lower transmissivity as compared to the UFA. Panday Demo. 25 below shows these interactions of pumping location and streamflow impact.



Panday Demo. 25 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

a. Impact of Groundwater Pumping from the non-UFA Aquifers in the Lower ACF River Basin where these Aquifers Underlie the UFA

75. I have estimated the streamflow impact of all pumping from the Claiborne, Clayton, and Cretaceous Aquifers where they are overlain by the UFA in the Lower ACF River Basin. As shown on Panday Demo. 26 below, pumping from these aquifers does not impact streams directly as they are separated from the streams by confining units and the aquifers overlying them.



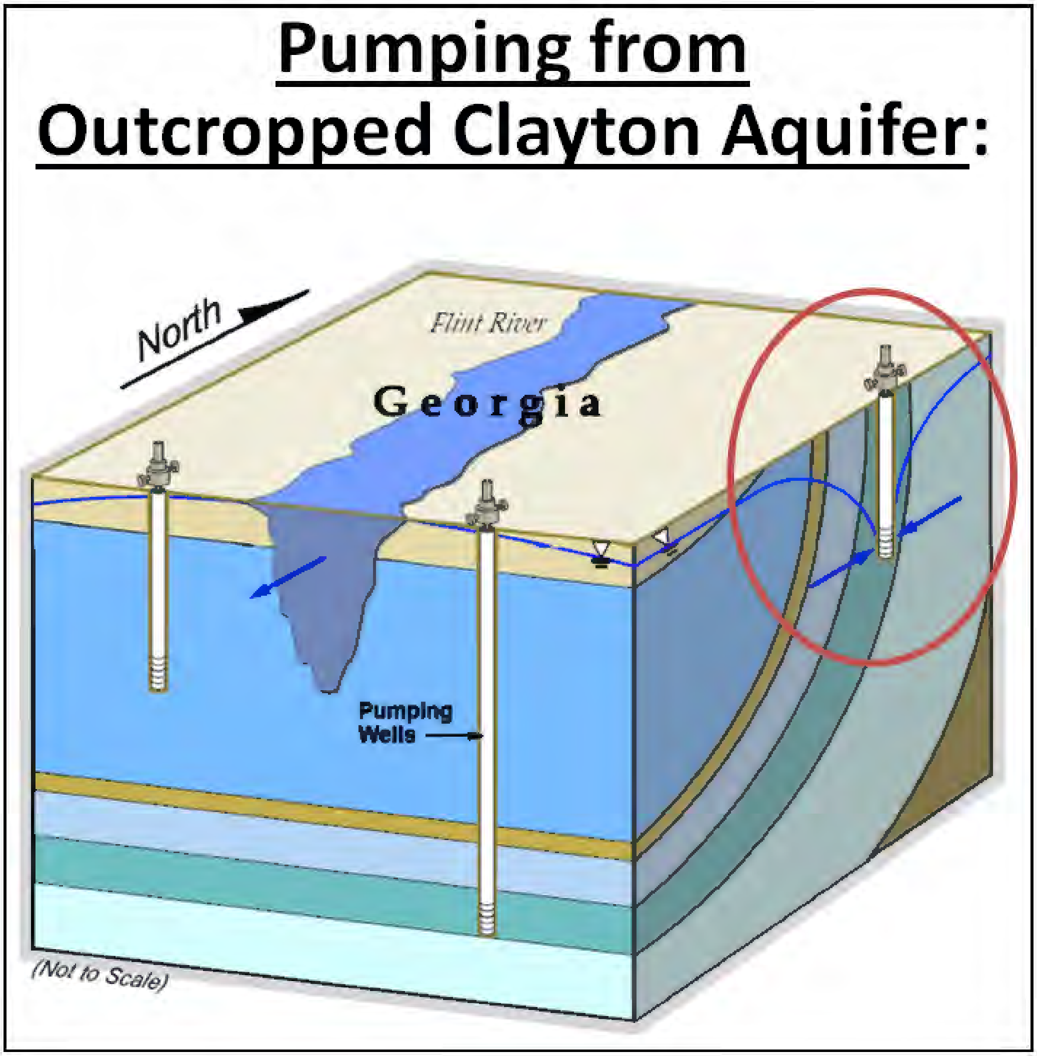
Panday Demo. 26 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

76. I have estimated that 51,361 acres of agricultural land was irrigated by pumping from all of the deeper (non-UFA) aquifers in the Lower ACF River Basin, which is about 12% of the total number of acres irrigated by pumping from the UFA. The maximum monthly impact of pumping for this UFA irrigated acreage within the basin in Georgia (plus a small addition due to M&I pumping from the UFA) was a streamflow reduction of 511 cfs in July for dry conditions with 2011 acreages. I contend that the impact of pumping in deeper aquifers is negligible, but even if I were to assume a connectivity of 10% of the impact of UFA pumping, as was done by Dr. Langseth's February 29th expert report, the impact of pumping from all the other aquifers would be a maximum of 6.1 cfs in July (10% of 12% of 511 cfs). It is important to note that the 10% of UFA pumping criterion mentioned by Dr. Langseth was only for pumping from the Claiborne Aquifer, while the other deeper aquifers would have even less connectivity.

Therefore, my evaluation generally overstates the impact on streamflow from pumping in these aquifers where they underlie the UFA.

b. Impact of Groundwater Pumping from the non-UFA Aquifers in the Upper and Middle ACF River Basin where these Aquifers Outcrop

77. To the north of where the UFA exists, the Claiborne, Clayton, and Cretaceous Aquifers reach the surface (outcrop). In those outcrop areas, the streams and rivers are directly incised into these aquifers as shown on Panday Demo. 27 below.



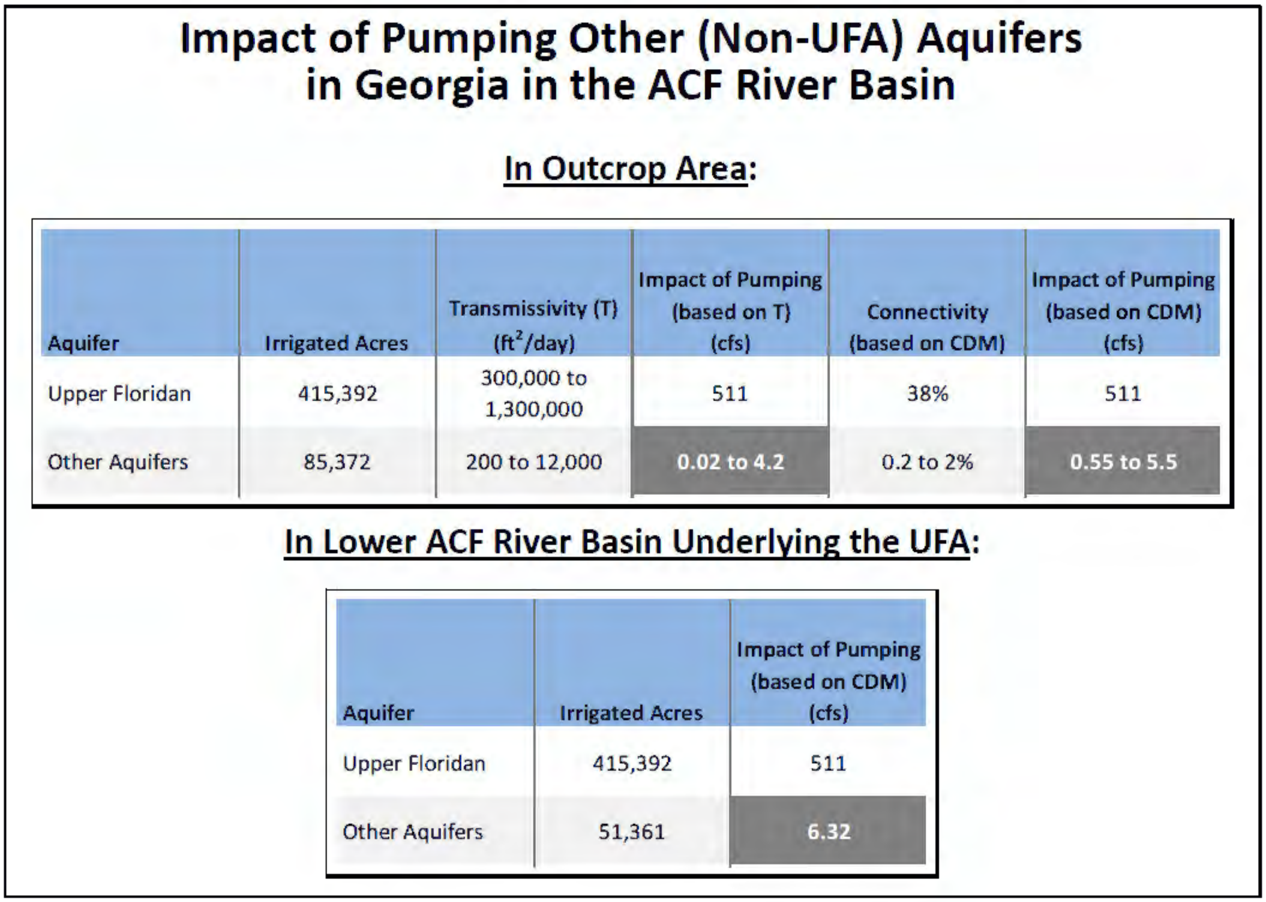
Panday Demo. 27 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

78. However, the connectivity of these aquifers to the streams is much smaller than that of the UFA, because the transmissivity of these aquifers is significantly smaller. Also,

because these aquifers have a smaller transmissivity, the connectivity diminishes more rapidly with distance from the streams than the UFA. As a result, the impact of pumping from these aquifers on groundwater flow to streams in the ACF River Basin is negligible in comparison to the streamflow impacts due to pumping from the UFA.

79. The transmissivity values for the various aquifers in the Basin were shown earlier on Panday Demo. 6. The transmissivity of the UFA is noted to be 25 to 6,500 times larger than for the other aquifers indicating a comparatively larger connectivity since flow is proportional to transmissivity (a fundamental hydrogeologic principle known as Darcy's Law). I estimated that 85,372 acres were irrigated by pumping from all the other aquifers in the Upper and Middle ACF River Basin, which is about 20% of the UFA-irrigated 415,392 acres in the Basin. The maximum monthly impact of pumping for this UFA-irrigated acreage in Georgia (and a small addition due to M&I pumping from the UFA) was a streamflow reduction of 511 cfs in July for dry conditions with 2011 acreages. Thus, if the impact of pumping from these other aquifers in the outcrop areas were proportional to their transmissivity, the streamflow impact of this pumping would be a maximum, of about 4 cfs in July (25 times less than 20% of 511 cfs).

80. I also performed another analysis of the impact of pumping from the non-UFA aquifers in the outcrop areas using the value of connectivity calculated by CDM (2012). For the Claiborne and Clayton Aquifers, CDM (2012) indicated a connectivity of 2% and 0.2% respectively, for the current distribution of pumping within these aquifers. My simulations of 2011 dry conditions indicated a 38% connectivity for the UFA. This is 19 times larger than the largest connectivity of 2% for the non-UFA aquifers in their outcrop locations. Therefore, the maximum impact to streamflow estimated from this analysis even with using the largest connectivity value of 2%, is 5.4 cfs in July (19 times less than 20% of 511 cfs). Panday Demo. 28 below summarizes my analyses for pumping these non-UFA aquifers where they underlie the UFA as well as in their outcrop locations where the UFA is absent.



Impact of Pumping Other (Non-UFA) Aquifers in Georgia in the ACF River Basin

In Outcrop Area:

Aquifer	Irrigated Acres	Transmissivity (T) (ft^2/day)	Impact of Pumping (based on T) (cfs)	Connectivity (based on CDM)	Impact of Pumping (based on CDM) (cfs)
Upper Floridan	415,392	300,000 to 1,300,000	511	38%	511
Other Aquifers	85,372	200 to 12,000	**0.02 to 4.2**	0.2 to 2%	**0.55 to 5.5**

In Lower ACF River Basin Underlying the UFA:

Aquifer	Irrigated Acres	Impact of Pumping (based on CDM) (cfs)
Upper Floridan	415,392	511
Other Aquifers	51,361	**6.32**

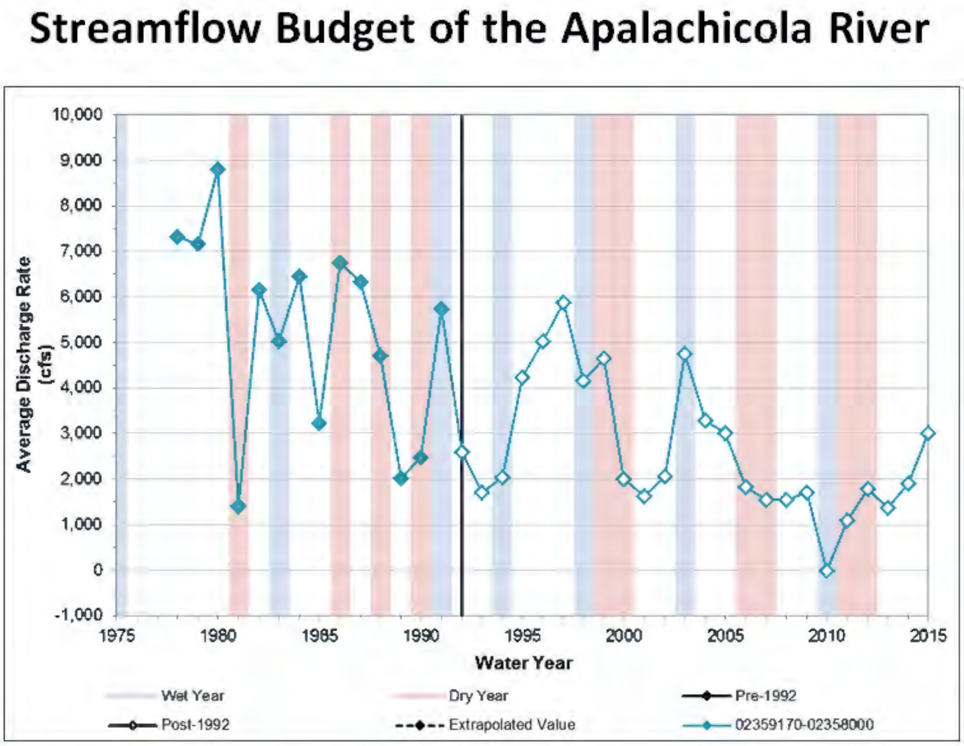
Panday Demo. 28 — Source: Panday Memorandum 22 July 2016.

81. The impact of pumping on streamflow depends on transmissivity as well as pumping location. Scaling of the impacts from groundwater pumping as I have done in this section provides estimates at best. Modeling can provide more accurate estimates of the impacts; however, the estimated impact to streamflow from pumping in these other aquifers is so small in comparison to the UFA pumping impacts that further refinement of these numbers is not warranted.

VI. FLORIDA'S CONTRIBUTION TO APALACHICOLA RIVER FLOW AT THE SUMATRA GAGE HAS DECLINED OVER TIME

82. I also evaluated the fate of water after it flows from Georgia into Florida. I analyzed the stretch of river (i.e., river reach) between the Chattahoochee Gage (which is the USGS gage that measures flows from Woodruff Dam into Florida), and the Sumatra Gage (which is the last USGS river gage before the Apalachicola Bay).

83. I first compared Sumatra and Chattahoochee Gage flows which showed an increased loss of water over time. In other words, Florida's contribution to the Apalachicola River and Bay was decreasing over time. For this analysis, I looked at the difference between flows at the downstream (Sumatra) gage and the flows at the upstream (Chattahoochee) gage. Thus, I evaluated how much water is being added to the Apalachicola River in Florida (including from the Chipola River) between the gages. Panday Demo. 29 below shows that Florida's contribution to streamflow in the Apalachicola River (difference between the annual average flows at Sumatra and Chattahoochee Gages) has declined over time. Before 1992, an average of 5,254 cfs was added to the Apalachicola River between the Chattahoochee and Sumatra Gages. However after 1992, that average has decreased to 2,614 cfs—a change of 2,640 cfs. Thus, since 1992, Florida has contributed an average of 2,640 cfs less water to the Apalachicola River and Bay than during the 1975-1992 time period.



USGS Station ID	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Average Discharge Rate (cfs)												
02359170-02358000	1,402	-15	3,591	1,683	5,950	2,019	6,670	3,499	8,801	5,868	5,254	2,614

Panday Demo. 29 — Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-6.

84. I also performed a water budget analysis over the Apalachicola River Basin area that lies between the Chattahoochee and Sumatra Gages in Florida. This analysis looks at the Apalachicola River Basin and not just the River, to further determine how other components of the water balance vary over the basin through time. Additional inflows to the basin (in addition to inflow to Florida at the Chattahoochee Gage) include precipitation over the basin area between the Gages, and inflow to the basin from the Chipola River. Additional outflows from the basin (in addition to outflow at the Sumatra Gage) include evapotranspiration (evaporation and plant transpiration) that occurs over the basin area or losses to groundwater. I estimated precipitation over this area using data from nearby rain gages. I estimated Chipola River inflows using information available at an upstream Chipola River Gage. Outflow from the basin, including evapotranspiration and other losses, were computed as the remainder of the water balance over the basin. This is a common procedure in hydrology to estimate components such as evapotranspiration over a basin, which is otherwise difficult to measure. Panday Demo. 30 below shows the inflow and outflow components of the water balance for the area within the Apalachicola River Basin that lies between the Chattahoochee and Sumatra Gages.

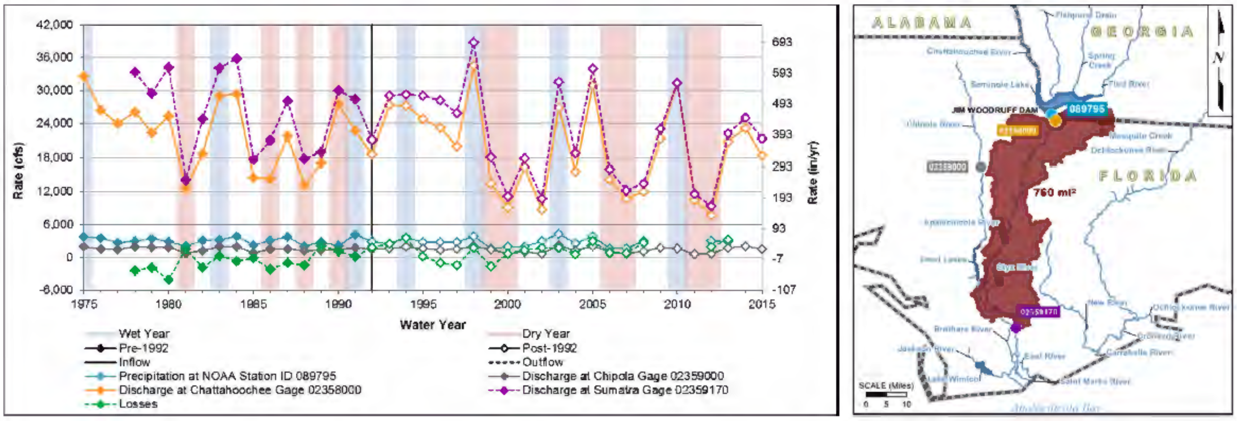
Apalachicola River Water Budget	
Inflows	**Outflows**
Chattahoochee Gage (USGS Station ID 02358000) **Chipola Gage (USGS Station ID 02359000)** **Precipitation (NOAA 089795 over basin area)**	Sumatra Gage (USGS Station ID 02359170) Other outflows or losses

Panday Demo. 30 – Inflow and Outflow Components of the Basin-Wide Water Budget Between Chattahoochee and Sumatra Gages.

85. My water budget analysis shown on Panday Demo. 31 below, indicates that Apalachicola River Basin outflow at the Sumatra Gage is less than combined inflows (flow at the Chattahoochee Gage, flow from the Chipola River, and precipitation). My analysis also shows that these losses have increased over time. For the pre-1992 period, the “other losses” term was

negative 13 inches/year (727 cfs) indicating that the basin was gaining water from groundwater and/or that there was less net evapotranspiration or other losses in the basin. For the post-1992 time period, an average net loss in the Apalachicola River Basin between the Gages, was 23 inches/year (1,276 cfs).

Water Budget Evaluation



	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Annual Precipitation (NOAA Station ID 089795)												
(cfs)	2,089	1,622	2,654	2,268	3,106	2,838	3,587	3,048	4,143	4,331	3,068	2,789
(in/yr)	37	29	47	41	55	51	64	54	74	77	55	50
Average Discharge Rate (cfs)												
02359000	785	569	1,378	964	1,511	1,513	1,864	1,786	2,011	2,186	1,531	1,411
02358000	12,661	7,605	17,041	13,085	22,697	19,295	26,452	25,340	32,718	34,617	22,231	19,461
02359170	14,063	9,384	19,552	15,406	28,262	21,833	32,566	29,067	35,843	38,763	26,306	22,075
Losses												
(cfs)	-4,045	-1,604	-1,838	624	-830	1,701	218	2,207	2,198	3,495	-727	1,276
(in/yr)	-72	-29	-33	11	-15	30	4	39	39	62	-13	23

Panday Demo. 31 –Water Budget Evaluation.

VII. DR. LANGSETH MAKES SYSTEMATIC MISTAKES THAT OVERSTATE THE IMPACT OF GROUNDWATER PUMPING ON STREAMFLOW

86. I generally agree with the opinion expressed in Dr. Langseth's expert report submitted February 29, 2016, that the current distribution and timing of pumping from the UFA results in about 38 to 40% average annual impact to streamflow. In other words, for every 100 cfs pumped from the UFA there are about 40 cfs less in the streamflow on an average annual basis. However, Florida has now abandoned that opinion. Florida's experts now claim that groundwater pumping has a much higher impact of 60% in the short term and 90% in the long term. These new values are unreliable because they are based on outdated groundwater models and on fundamental mischaracterizations of published reports.

A. Florida's "60% short-term impact factor" is inflated and unreliable because it is based on an outdated model.

87. Florida's experts now claim that groundwater pumping actually has an annual impact of 60%. Dr. Hornberger bases this new value on an older model that was developed by USGS (Torak and McDowell, 1996) which I used in the 1990s. (Direct Testimony of G. Hornberger, ¶¶ 98 and 100). Dr. Langseth also refers to my use of this same older model that was developed by USGS to support his new claim of a 60% impact factor (Direct Testimony of D. Langseth, ¶ 80). Their reliance on that older model is unreasonable because there is more up-to-date information available as I explain further below.

88. The older USGS model which Florida now relies on for its claimed impact of 60%, is outdated. When I conducted modeling in the 1990s to analyze the impact of groundwater pumping on streamflow, I used the best model available at that time: the Torak and McDowell (1996) MODFE model. That model gives a 60% impact. However, that model is now out-of-date and no longer reflects the USGS's best understanding of the UFA and groundwater pumping distribution. USGS has since released a new version of the MODFE model, which is based on more accurate data. This updated model—Jones and Torak (2006) MODFE model—is the model I used in my own analysis for this case.

89. The primary difference between the old and new models is the agricultural irrigation distribution. As I have described above, the location and timing of pumping has a profound impact on how that pumping affects streamflow. The old model was calibrated during a time when high-quality data on groundwater pumping was not available. As a result, USGS had to make rough estimates about how much water was being pumped from the UFA and at what locations.

90. USGS understood that the lack of statistically sound, scientifically based agricultural irrigation data was a serious shortcoming of the old model. To remedy that situation, USGS worked with Georgia EPD and the University of Georgia (UGA) to compile better information regarding the amount of groundwater pumping, the aquifer from which the water was being extracted, and the specific locations of those withdrawals. USGS coordinated with Dr. Hook from UGA to use actual readings from meters on groundwater pumps (about a 5

percent sampling of the wells in the Upper Floridan aquifer in the model domain) for estimating irrigation depths in the ACF River Basin. USGS also worked with Georgia EPD to update data related to location of withdrawals and total wetted acreage. The researchers then compiled this information into irrigation input datasets based on irrigated depths and specific acreage.

91. I have compared the old Torak and McDowell (1996) MODFE model with the updated Jones and Torak (2006) MODFE model. The range of transmissivities of the two models is similar. The main difference is that the pumping distributions in the two models are substantially different and this in turn results in different basin-wide baseflow impacts.

92. In short, while the study I conducted in the 1990s was based on the best available data at that time, it is no longer valid. USGS now has more accurate data about irrigation locations and amounts. The more updated information gives an impact factor value of about 40%.

B. Florida's monthly "conversion factor" artificially inflates the impact of groundwater pumping on streamflow in June.

93. In their direct testimony, Florida's experts calculate impact to streamflow in "peak summer months" by using a monthly "conversion factor" to convert annual impact to streamflow into peak monthly impacts. (Direct Testimony of D. Sunding, ¶ 48). The process by which these factors were developed is flawed and exaggerates the impact of pumping on streamflow in the month of June. The basic problem with the approach is the same as with my other critiques—Florida did not conduct any independent numerical groundwater flow modeling that can calculate such impacts. Instead, they misapply or manipulate scaling procedures and scaling factors, which leads to exaggerated impacts to streamflow.

94. Florida's monthly "conversion factors" are based on the ratio of the amount pumped in a month to the monthly impact to streamflow in that same month, as published in Jones and Torak (2006). The impact from pumping on streamflow in any given month is the cumulative effect of pumping throughout the year; therefore, these monthly conversion factors are only valid if the timing and distribution of pumping for the ***entire year*** is consistent with the pumping that was actually modeled by Jones and Torak (2006). In other words, those ratios will

only be accurate if both the pumping location and timing is consistent. Florida's scenarios do neither.

95. The error with Florida's approach is that they use a mix-and-match of impact factors from one pumping schedule, with pumping of another pumping schedule. The "conversion" computations of Florida's experts are illustrated in Panday Demo. 32 below which was Table D.2 in Dr. Hornberger's Report of 29 Feb, 2016.

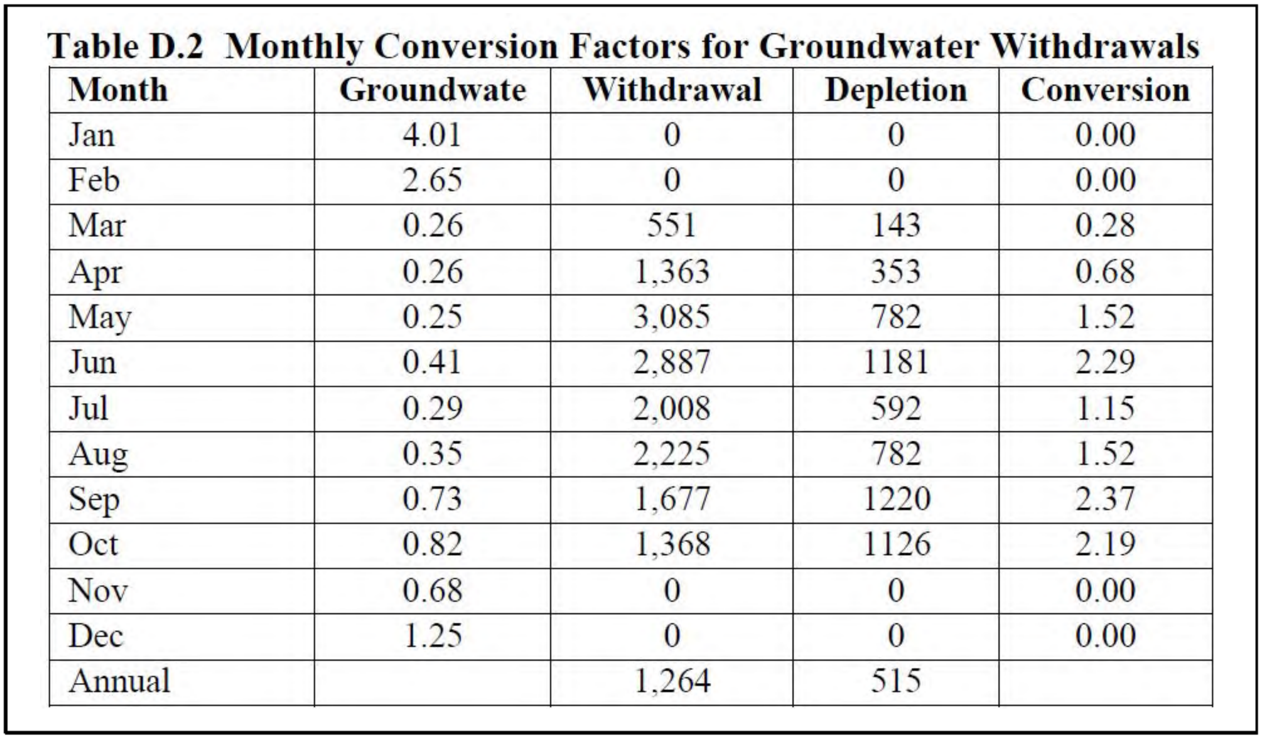


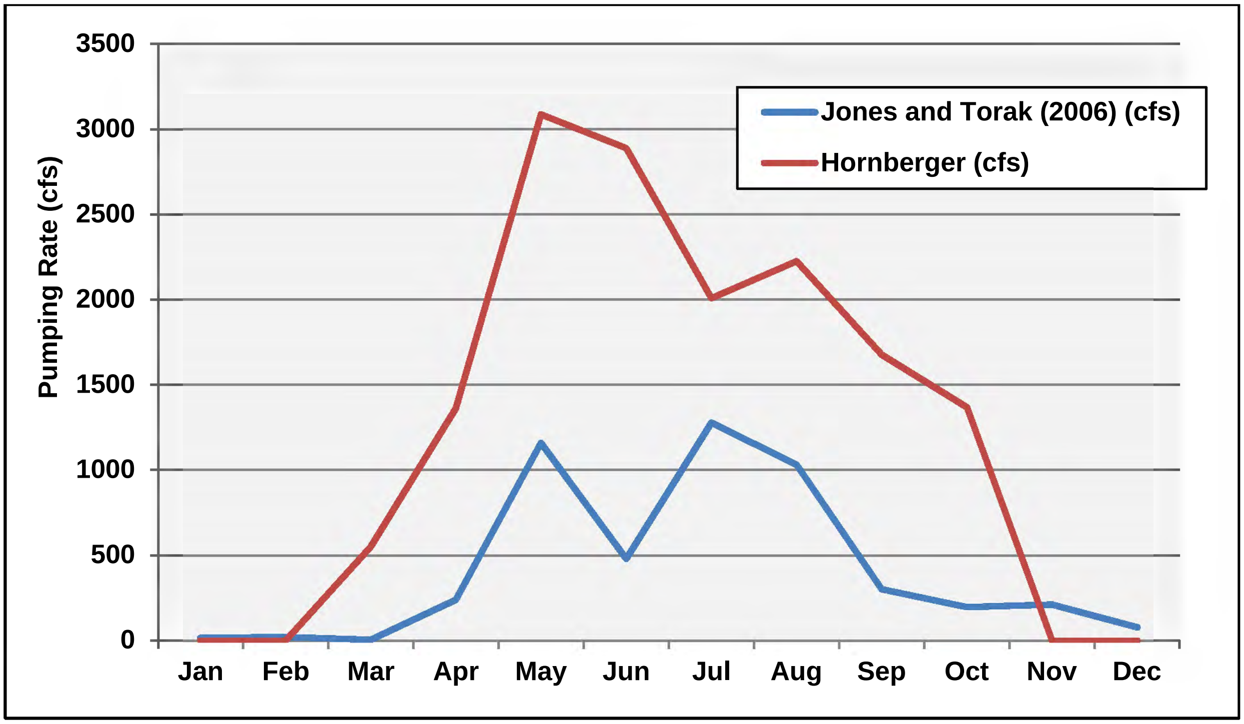
Table D.2 Monthly Conversion Factors for Groundwater Withdrawals

Month	Groundwate	Withdrawal	Depletion	Conversion
Jan	4.01	0	0	0.00
Feb	2.65	0	0	0.00
Mar	0.26	551	143	0.28
Apr	0.26	1,363	353	0.68
May	0.25	3,085	782	1.52
Jun	0.41	2,887	1181	2.29
Jul	0.29	2,008	592	1.15
Aug	0.35	2,225	782	1.52
Sep	0.73	1,677	1220	2.37
Oct	0.82	1,368	1126	2.19
Nov	0.68	0	0	0.00
Dec	1.25	0	0	0.00
Annual		1,264	515	

Panday Demo. 32 — Table D.2 from Hornberger Expert Report (FX-0785), 29 February 2016.

96. Dr. Hornberger's monthly withdrawal schedule deviates from the pumping schedule of Jones and Torak (2006) as noted in Panday Demo. 28 below, and thus it overstates the impact of pumping in June. The "Groundwater" factors in Panday Demo. 32 above, are the ratio of depletion-to-pumping for each month (pumping is the denominator). The Jones and Torak (2006) model implements a relatively small amount of pumping in June compared to the rest of the summer months. Therefore, in June, these ratios tend to show higher relative impact to streamflow—but only because ***pumping is so low*** in the Jones and Torak (2006) study as compared to Dr. Hornberger's pumping values (see dip in blue line in June, in Panday Demo. 33

below). This is why Dr. Hornberger's calculated June "conversion factor" of 2.29 is so much larger than any other summer month.[4]



Panday Demo. 33 — Comparison of Pumping Distributions from Jones and Torak (2006) (JX-018) and Hornberger (29 February 2016, Table D.2) (FX-0785).

97. Florida's testimony presents a number of potential scenarios that involve changes to groundwater pumping patterns, including: i) improving irrigation efficiency; ii) reducing early season pecan irrigation; and iii) moving irrigation for high value crops to deeper aquifers. Each of those scenarios changes the spatial and temporal pumping patterns. Thus, there is no appropriate way to use "conversion factors" or scaling procedures to analyze the impact of those scenarios. Only running the numerical model with these complex conditions incorporated into it can provide such results.

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[4] The "conversion factors" are also large in September and October because Jones and Torak (2006) estimated pumping in those months to be very small. Dr. Hornberger also ignores pumping in January, February, November and December when the Groundwater factors are very high (because Jones and Torak estimated some pumping, but very little).

Dr. Langseth's direct testimony also purports to rely on my 20-year-old report and claims that *"Dr. Panday's 1998 modeling resulted in a seasonal factor for June of about 2.3."* (Direct Testimony of D. Langseth, ¶ 84). But the pumping distribution I used in that model was not a real pumping distribution — it was a simple sine curve since monthly pumping data was unavailable. Florida's reliance on that value is entirely unwarranted.

C. Florida's "90% long-term impact factor" is not based on any analysis or modeling.

98. Dr. Hornberger testified that *"the long-term impact factor in the Upper Floridan Aquifer is 90% or higher."* (Direct Testimony of G. Hornberger, ¶ 99). This is not based on independent modeling. Dr. Hornberger instead cites "fundamental hydrologic principles" without any further detail. Fundamental hydrologic principles have been applied by modelers evaluating streamflow reduction in the basin for decades now and none of them have ever come up with an impact factor even close to 90%. Dr. Hornberger also cites a single report published in 1983 to back up this number without further background or context. This outdated, hypothetical simulation cited by Dr. Hornberger does not reflect the realities of the Lower ACF River Basin.

99. To the extent Dr. Hornberger is relying on Dr. Langseth's discussion of this issue in his "Pumped Water Source Notes" (FX-585), Dr. Langseth's analysis is incorrect. First, he fundamentally mischaracterizes the simulation results of Jones and Torak (2006). The premise of Dr. Langseth's "note" was that at the end of the Jones and Torak model simulation, the change in aquifer storage (water levels) would have to be replaced. Dr. Langseth claimed that *"when the lowered groundwater levels are restored, the water used to restore those levels does not flow to the stream causing additional streamflow depletions"* (Langseth Direct Testimony, ¶ 31). But the model already simulates this aquifer replenishment as well as its impact to baseflow during the winter months when there is little to no irrigation pumping. Dr. Langseth also claims that replenishing aquifer storage would come entirely from groundwater contribution to streamflow. This is just conjecture on his part. The aquifer is ultimately replenished from several sources including what would have otherwise gone to peak storm runoff, evapotranspiration and overburden storage (the water-holding layer above the UFA). Dr. Langseth has not conducted modeling or any form of analyses to determine this; instead, he incorrectly attributes all changes in aquifer storage solely to reduced contribution of groundwater to streams and rivers.

100. I have not conducted a modeling analysis of long-term (10-year) impacts. Georgia EPD, USGS, and other entities interested in understanding baseflow impacts of pumping the UFA, also do not perform such analyses; nor do they provide simplistic explanations of such long-term impacts. This is because streamflow concerns are related to conditions of low-flow

during peak irrigation season or during drought periods of 1 to 2 years and do not last for 10-year time spans.

D. Dr. Langseth's impact factors for non-UFA aquifers are overstated.

101. Dr. Langseth developed average annual impact factors for non-UFA aquifers that significantly overstate their impact on streamflow. (Direct Testimony of D. Langseth, ¶ 87). He estimates annual impact factors of approximately 30% for the Claiborne Aquifer and about 20% for the Clayton and Cretaceous Aquifers. These values are not correct. . First, the impact of pumping from these other aquifers would depend on whether pumping of these aquifers occurs where underlie the UFA in the Lower ACF River Basin or whether the pumping is in the outcrop areas of the respective aquifers further north.

102. Where the UFA overlies these other aquifers, the impact to streamflow of pumping from them is negligible as they are separated from the UFA by confining units and are not incised by the streams and Rivers of the Basin. As I have discussed earlier (¶ 76), even if I use a connectivity value from Dr. Langseth's February 29th expert report, the net resulting impact of current pumping from these deeper aquifers is about 6 cfs.

103. Where the UFA does not exist, Dr. Langseth misinterprets a modeling study by CDM to show between 65% to nearly 100% impact to streamflow from pumping in non-UFA aquifers, by computing impacts at select river reaches – his analysis gives numbers greater than 100% if he applies it model-wide as noted in the CDM study. Obviously his interpretation is incorrect, especially since pumping from the UFA has an impact of only about 40% of the pumping rate, and the impact for the Claiborne, the Clayton, and the Cretaceous Aquifers are lower (in that order). Dr. Langseth admits as much in his expert report. He also testified in his deposition that: "I thought it was not reasonable to have the transient impact factor for the Claiborne being higher than that for the Upper Floridan." Langseth Dep. Tr. 796:20-24.

104. Because his interpretation of the CDM studies gave him unacceptable results, Dr. Langseth arbitrarily assigned his impact factors for the Claiborne, Clayton, and Cretaceous aquifers without any modeling or quantitative justification aside from the constraint that they be less than that of the UFA. This is not a sufficient basis to support his annual impact factor values for these aquifers. Instead, I have correctly interpreted the impact factors in the CDM studies

which give similar results for impact of pumping to streamflow as my alternative evaluation based on comparing the aquifer transmissivities (see Panday Demo. 28 above). .

VIII. DR. SUNDING'S PROPOSED BENEFITS ARE NOT POSSIBLE

105. Dr. Sunding proposes a number of conservation scenarios, but his "peak summer streamflow" benefits are not possible to achieve—even when eliminating all irrigation in the ACF River Basin. Even Dr. Langseth found that eliminating all irrigation from surface water and groundwater pumping in the UFA is not enough to create the streamflow Dr. Sunding claims to generate through his conservation scenarios. Further Dr. Sunding's reliance on Dr. Hornberger's "monthly conversion factor" causes him to report inflated monthly impacts to streamflow.

A. Dr. Sunding overstates the potential benefits from deficit irrigation.

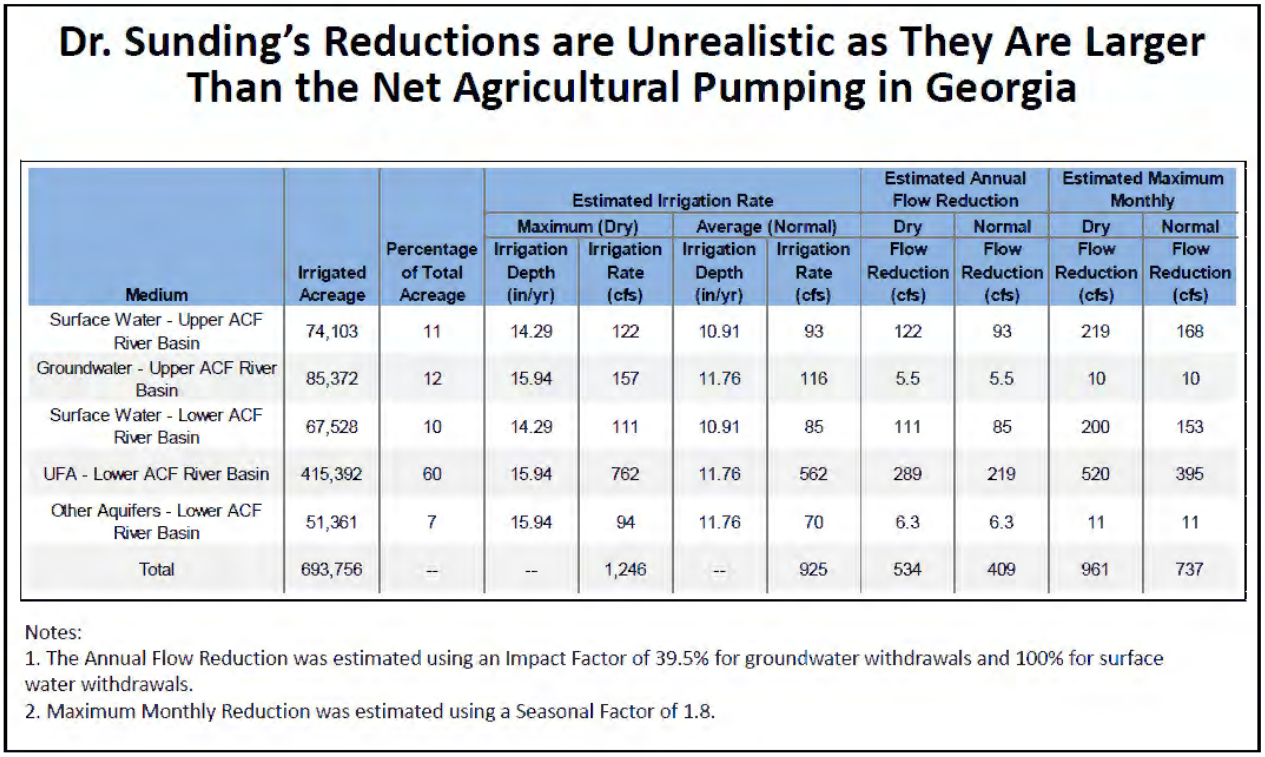
106. Dr. Sunding's most aggressive scenario claims to achieve an increase of up to 1,685 peak monthly flows from reductions in irrigation pumping alone, which is not possible.

107. During his deposition, Dr. Langseth testified that using his representative drought year, and eliminating all surface water used for irrigation in the entire ACF River Basin, would lead to an increase of a peak monthly streamflow of 636 cfs in June. Dr. Langseth further testified during his deposition that eliminating all groundwater pumping from the UFA would result in a peak streamflow of 616 cfs in September. Thus, even Florida's own experts estimate that eliminating ***all agricultural pumping from surface water and the UFA*** can only lead to a peak monthly increase of 1,252 cfs (636 cfs from surface water and 616 cfs from groundwater). Dr. Sunding's proposals that purport to generate an additional 1,500 cfs or more in peak monthly streamflow are impossible and inconsistent even with Florida's own expert's estimates.

108. Dr. Langseth's written testimony changes these numbers, but even under his new, inflated values, elimination of all irrigation from surface water and the UFA cannot generate the values claimed by Dr. Sunding. Florida's experts recently changed their position and now claim that the UFA has a connectivity of 0.6 (60%). Dr. Langseth's direct testimony uses the highest year of irrigation (2007), with the inflated annual impact factor of 0.6, and the exaggerated monthly conversion factor of 2.3. Despite using Florida's highest annual pumping values and

other impact factors that exaggerate the impact to streamflow, Dr. Langseth concludes that elimination of all groundwater pumping from the UFA would result in peak streamflow gain of 1,040 cfs in June. Thus, using Dr. Langseth's peak surface water pumping impact of 636 cfs, elimination of all irrigation from surface water and groundwater pumping in the UFA would have a peak impact of 1,676 cfs — ***still lower than Dr. Sunding's estimated gains from "conservation."***

109. My evaluation of the impacts shows that elimination of all irrigation pumping in the basin throughout the year (including groundwater and surface-water) would result in a peak monthly increase of 961 cfs for drought conditions and 737 cfs for normal conditions as I further discuss below.



Dr. Sunding's Reductions are Unrealistic as They Are Larger Than the Net Agricultural Pumping in Georgia

Medium	Irrigated Acreage	Percentage of Total Acreage	Estimated Irrigation Rate				Estimated Annual Flow Reduction		Estimated Maximum Monthly	
			Maximum (Dry)		Average (Normal)		Dry	Normal	Dry	Normal
			Irrigation Depth (in/yr)	Irrigation Rate (cfs)	Irrigation Depth (in/yr)	Irrigation Rate (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)
Surface Water - Upper ACF River Basin	74,103	11	14.29	122	10.91	93	122	93	219	168
Groundwater - Upper ACF River Basin	85,372	12	15.94	157	11.76	116	5.5	5.5	10	10
Surface Water - Lower ACF River Basin	67,528	10	14.29	111	10.91	85	111	85	200	153
UFA - Lower ACF River Basin	415,392	60	15.94	762	11.76	562	289	219	520	395
Other Aquifers - Lower ACF River Basin	51,361	7	15.94	94	11.76	70	6.3	6.3	11	11
Total	693,756	--	--	1,246	--	925	534	409	961	737

Notes:
1. The Annual Flow Reduction was estimated using an Impact Factor of 39.5% for groundwater withdrawals and 100% for surface water withdrawals.
2. Maximum Monthly Reduction was estimated using a Seasonal Factor of 1.8.

Panday Demo. 34— Source: Panday Expert Report (GX-0873), 20 May 2016,
Revised Table C-8, and Tables F-1 and F-2.

110. Panday Demo. 34 above shows my evaluation of basin-wide irrigation water use and resulting impact to streamflow. The maximum monthly impact of UFA pumping in the Basin was a streamflow reduction of 520 cfs. My evaluation of the impact of pumping from the other aquifers in the ACF River Basin indicates approximately 22 cfs of maximum monthly

reduction to streamflow. Also, from my analysis of the database for irrigated acreages from 2008-2011 provided by Georgia EPD, approximately 21% of the total irrigated acreages in the ACF River Basin are being irrigated with surface water. For a dry year (where irrigation depths are 14.29 in/yr), the total surface water irrigated acreages (141,631 acres from the Georgia EPD database of 2008-2011) would consume approximately 233 cfs annually. With a Seasonal Factor of 1.8, that would be a maximum consumption of 419 cfs from surface water. Therefore, assuming all surface water withdrawals for irrigation were entirely eliminated along with all groundwater withdrawals, there would be peak monthly increase of only 961 cfs (520 cfs plus 22 cfs plus 419 cfs) for dry 2011 pumping conditions. The numbers in Panday Demo. 34 above are slightly different (about 1 cfs off) due to round-off during calculations.

111. Dr. Sunding seems to assume that if he stops pumping during the peak month, the full impact to streamflow will be immediate. That is incorrect. If you stop pumping for one month, you do not recover all that month's resulting baseflow reduction right away. This is because of the time-lag effect (discussed above in Section IV.H) that causes only about 50% of a month's pumping impact to be recovered by the end of the month. Furthermore, the impact of previous months' pumping is also incurred during the month when pumping is stopped; that impact depends on the pumping rates during those previous months. These interactions between pumping changes through the months and the time-lag effect associated with storage in the aquifer are complicated; only simulations using a numerical groundwater model can assess the ultimate impact of shutting off pumping for only the peak month. The scaling methodology is invalid if the pumping distributions or schedules are changed as I have noted in my expert report, my deposition testimony, and this testimony.

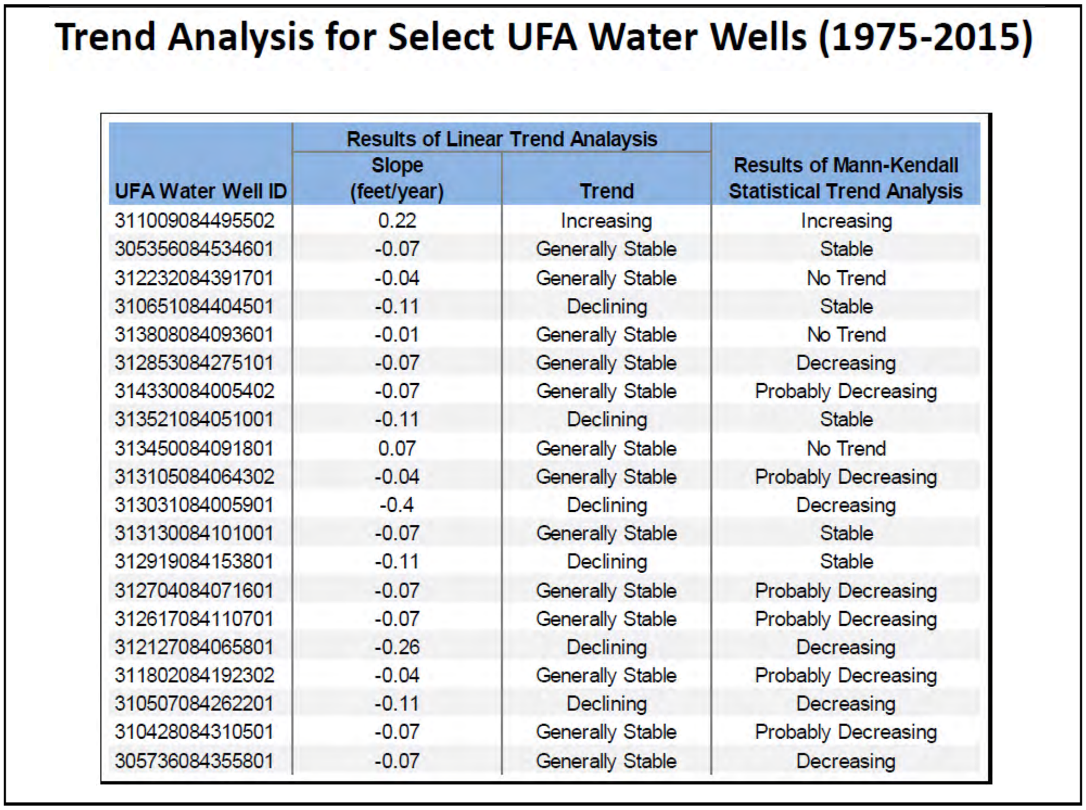
IX. THERE IS NO EVIDENCE THAT GROUNDWATER PUMPING IN THE LOWER ACF RIVER BASIN IS CAUSING LONG-TERM DEPLETION OF THE UFA

112. Dr. Hornberger and Dr. Langseth spend considerable time in their direct testimony discussing groundwater level trends. First, I have analyzed groundwater levels in the UFA and conclude that there are no basin-wide trends. Second, purported changes in groundwater levels in Georgia are not directly related to the ultimate issue in this case—streamflow reductions to Florida resulting from pumping in Georgia. Third, Florida presents no

evidence or analyses indicating that changes in water levels (be they weather- or pumping-induced) have or will have any substantive impact on streamflow. I have modeled the impact of a hypothetical lowering of basin-wide water levels, and I found that the potential impacts are relatively small.

A. There is no long-term, basin-wide trend in groundwater levels of the UFA.

113. I have conducted two types of trend analysis on groundwater levels since the 1970s to determine if groundwater levels have declined in the UFA. To understand long-term trends and whether pumping has impacted groundwater levels, the best time-frame to analyze is from 1975 to the present day because this allows me to analyze the relative change in water levels at a multi-year scale, as irrigation pumping increased significantly from the 1970s through the 1990s and somewhat leveled off subsequently. First, I conducted a linear trend analysis of groundwater levels in select UFA water wells. As shown on Panday Demo. 35 below, the linear trend analysis of available data between 1975 and 2015 indicated a “declining” trend at only 6 wells and an “increasing” trend at 2 wells, with “generally stable” groundwater levels at the remaining 12 wells. I have defined “generally stable” trends as those wells with water levels showing a linear trending slope of less than 1 foot change in 10 years.



Trend Analysis for Select UFA Water Wells (1975-2015)

UFA Water Well ID	Results of Linear Trend Anaalysis Slope (feet/year)	Trend	Results of Mann-Kendall Statistical Trend Analysis
311009084495502	0.22	Increasing	Increasing
305356084534601	-0.07	Generally Stable	Stable
312232084391701	-0.04	Generally Stable	No Trend
310651084404501	-0.11	Declining	Stable
313808084093601	-0.01	Generally Stable	No Trend
312853084275101	-0.07	Generally Stable	Decreasing
314330084005402	-0.07	Generally Stable	Probably Decreasing
313521084051001	-0.11	Declining	Stable
313450084091801	0.07	Generally Stable	No Trend
313105084064302	-0.04	Generally Stable	Probably Decreasing
313031084005901	-0.4	Declining	Decreasing
313130084101001	-0.07	Generally Stable	Stable
312919084153801	-0.11	Declining	Stable
312704084071601	-0.07	Generally Stable	Probably Decreasing
312617084110701	-0.07	Generally Stable	Probably Decreasing
312127084065801	-0.26	Declining	Decreasing
311802084192302	-0.04	Generally Stable	Probably Decreasing
310507084262201	-0.11	Declining	Decreasing
310428084310501	-0.07	Generally Stable	Probably Decreasing
305736084355801	-0.07	Generally Stable	Decreasing

Panday Demo. 35 — Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-4.
Data was obtained from the USGS (JX-128). Groundwater level hydrographs are included with the Panday Demo. 35 attached to this testimony.

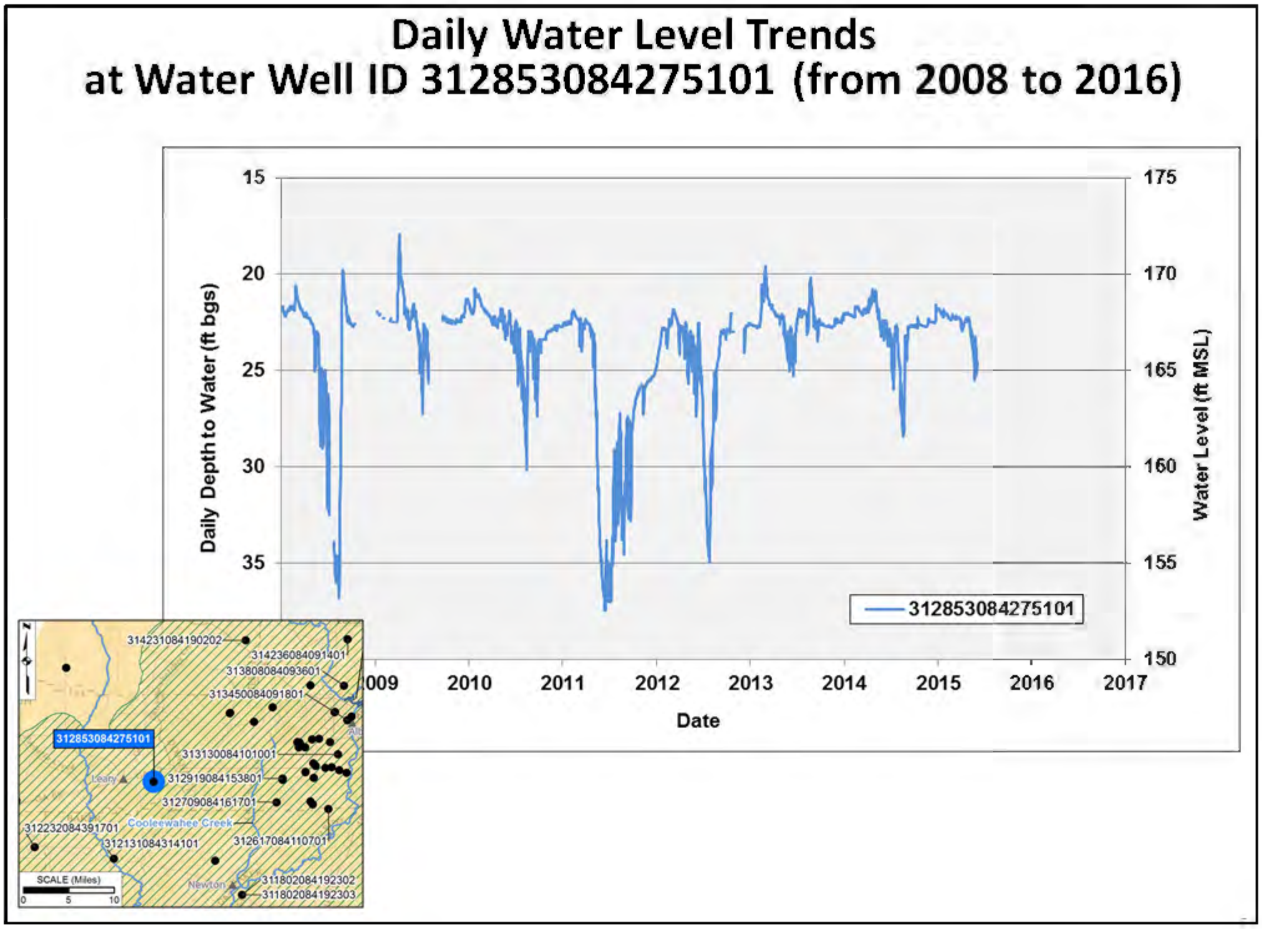
114. I also conducted a Mann Kendall statistical trend analysis of groundwater levels in select UFA water wells, which indicated that the groundwater level trends were mostly "stable," "no trend," or "probably decreasing" (i.e., some indication of trend, but not statistically significant). There were some wells that trended as "increasing" and some as "decreasing".

115. Both analyses indicated that there was no overall basin-wide trend in groundwater levels from 1975-2015. The "declining" and "probably declining" trend noted in some of the wells is likely the result of localized impacts, decreased precipitation, and more frequent, longer duration droughts noted since 1998.

B. Groundwater levels in the UFA fall during the summer months but rebound during the winter months.

116. Seasonal groundwater trends show that groundwater levels in the UFA respond to precipitation, drought, evapotranspiration, changes in surface water levels, and groundwater

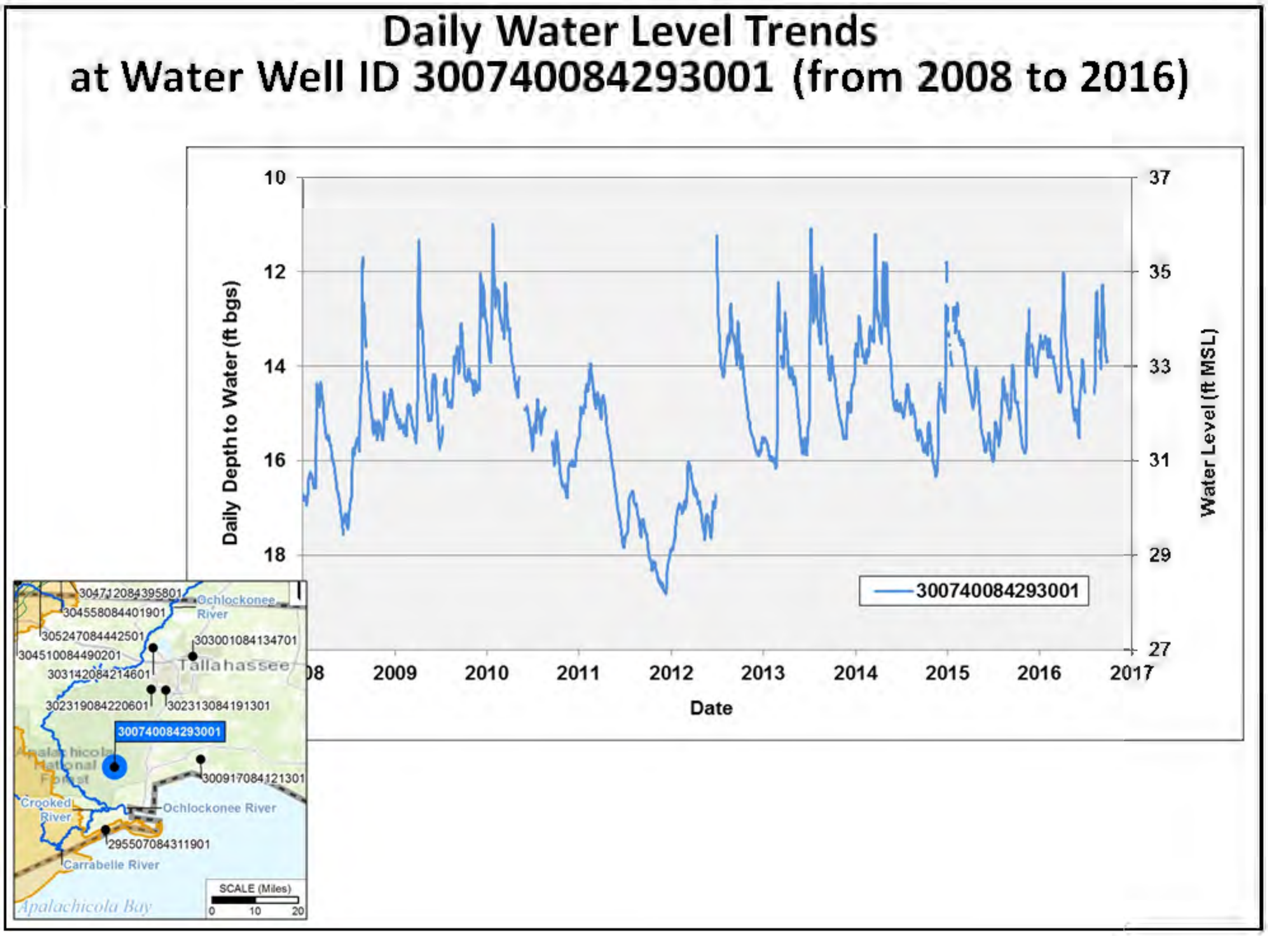
pumping in a seasonal manner. Lower water levels during the dry summer months will rise rapidly during the wetter winter months to about the same level each year, except during prolonged droughts—this has been noted in the pre-irrigation period record as well. The seasonal rebound of the UFA may be partial during extended drought conditions (as noted in the daily water level hydrographs for 2011 and 2012 on Panday Demo. 36 below), but groundwater levels in the UFA generally return to normal with the return of normal precipitation conditions. This has been noted in the literature (e.g., Jones and Torak, 2006) and is also acknowledged by Dr. Langseth. (Expert Report of D. Langseth, 29 February 2016)



Panday Demo. 36 — Daily Water Level Trends for a UFA Monitoring Well in the Georgia portion of the Lower ACF River Basin (USGS Well ID 312853084275101) (JX-128).

117. As shown in Panday Demo. 37 below, this same "partial-rebound" pattern can also be observed in daily water level hydrographs during 2011 and 2012 in data from a UFA water well located near Crawfordville, Fla. If Georgia's water consumption was the primary

driver in changes to groundwater levels, I would expect to see stark differences between UFA water levels in Florida and Georgia. Instead, the water level data shows patterns in Florida similar to water levels in Georgia, which suggests that regional weather is the primary driver of water level change and rebound, not pumping in Georgia.

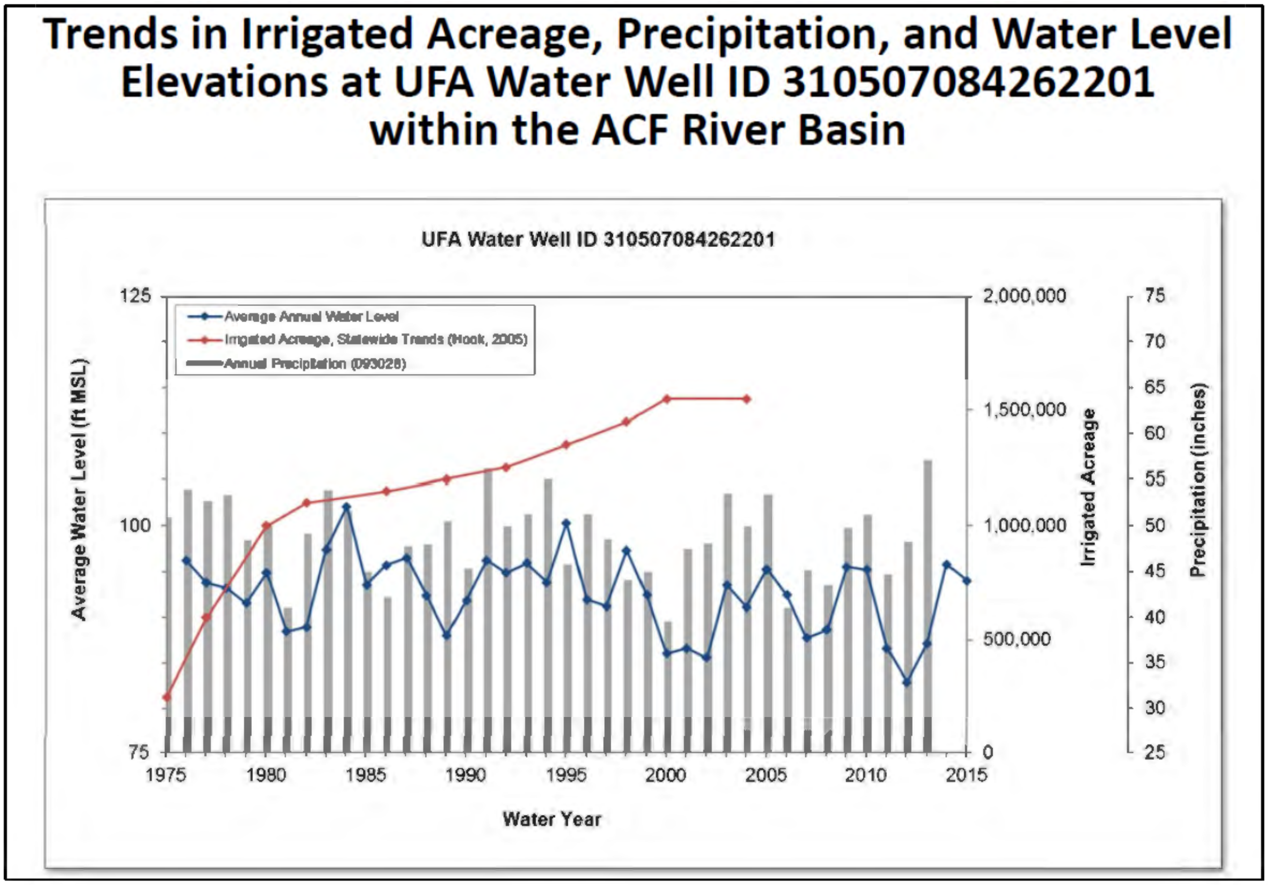


Panday Demo. 37 — Daily Water Level Trends for a UFA Monitoring Well near Crawfordville, Florida, Located just East of the Lower ACF River Basin (USGS well ID 300740084293001) (JX-128).

C. Weather—not pumping—has the largest impact on long-term groundwater levels in the ACF River Basin.

118. Dr. Langseth claims that groundwater pumping is responsible for changes in groundwater levels, but he does not conduct any analysis to attempt to isolate the impacts of pumping and weather conditions. I wanted to understand long-term trends in the ACF River Basin and what impact—if any—the increase of irrigation since the 1970s has had on UFA groundwater levels.

119. I first analyzed water level, precipitation, and irrigation acreage trends from 1975 to 2015. That analysis demonstrated that long-term groundwater levels are more responsive to changes in weather than groundwater pumping. Panday Demo. 38 below shows the annual groundwater level hydrograph for a well in the UFA (USGS well ID 310651084404501), the state-wide trend in irrigated acreages, and annual precipitation values.

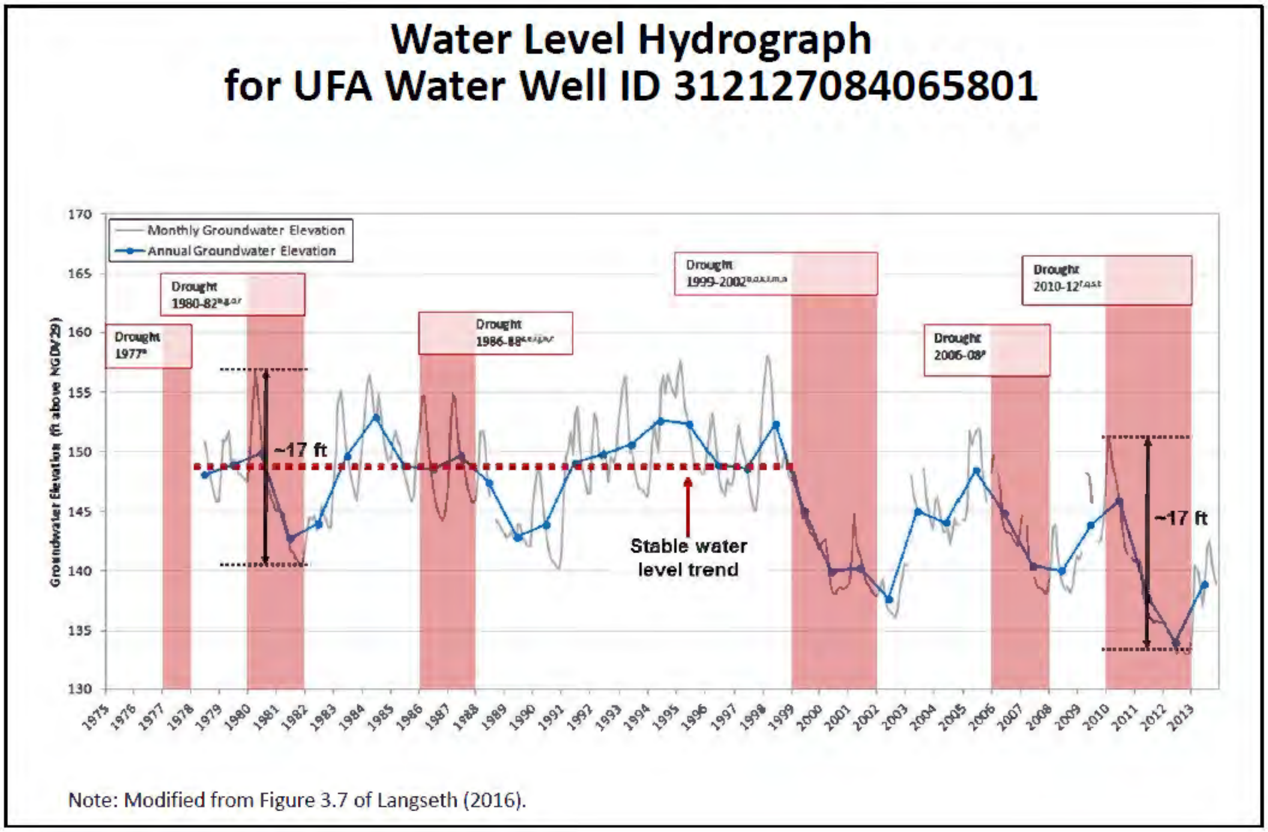

Trends in Irrigated Acreage, Precipitation, and Water Level Elevations at UFA Water Well ID 310507084262201 within the ACF River Basin

Panday Demo. 38 — This demonstrative shows the long-term growth of irrigated acreage in the State of Georgia and compares that trend with groundwater elevation and precipitation.

120. As shown in Panday Demo. 38 above, water levels respond to changes in precipitation-driven recharge rather than pumping. The largest increase in groundwater pumping was from the mid-1970s through the late-1990s. If groundwater irrigation pumping was having a significant impact on groundwater levels, I would expect to see groundwater levels fall in response to that substantial pumping increase. However the general trend in water levels does not decline over those years. Instead, water levels generally follow every increase or decrease in precipitation-driven recharge. The largest water level declines correspond to the recent back-to-

back droughts when precipitation-induced recharge was at its lowest. This shows that long-term water levels are much more responsive to changes in precipitation than changes in irrigated acreages and associated pumping since the 1970s.

121. Dr. Langseth claims that long-term groundwater levels in the UFA are generally declining at long-term rates of up to 17 ft/year during the 2010-2011 drought (Langseth Direct Testimony, ¶ 35) and that somehow it is a result of increased pumping within Georgia. This 17 ft/year decline was not a long-term decline and only occurred during the 2010-2012 drought. In fact, a 17 ft/year decline was also noticed during the 1980-1982 drought period, when pumping and irrigated acreages in Georgia was substantially lower (see Panday Demo. 39 below). Panday Demo. 39 further shows that groundwater levels in the well continued to display a generally stable trend from the late 1970s through the drought of the early 2000s even though there was significant expansion of agricultural irrigation pumping within Georgia during that time period.



Water Level Hydrograph
for UFA Water Well ID 312127084065801

Note: Modified from Figure 3.7 of Langseth (2016).

Panday Demo. 39 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 6-2.

122. To further analyze whether increases in groundwater pumping from the mid-1970s to the late 1990s impacted groundwater levels, I analyzed trends in water levels for the same wells as my 1970-2015 analysis, but split the data into pre-1998 and post-1998 values as noted on Panday Demo. 40 below. I chose 1998 because irrigation pumping has increased significantly from the 1970s through the 1990s and somewhat leveled off subsequently. This leveling off was also observed by Florida's experts.[5] Another reason for selecting 1998 is that droughts were of longer duration, more frequent and more severe after 1998 and thus I could evaluate groundwater levels during the period with large pumping increases pre-1998, independently from the period with more severe dry conditions post-1998.

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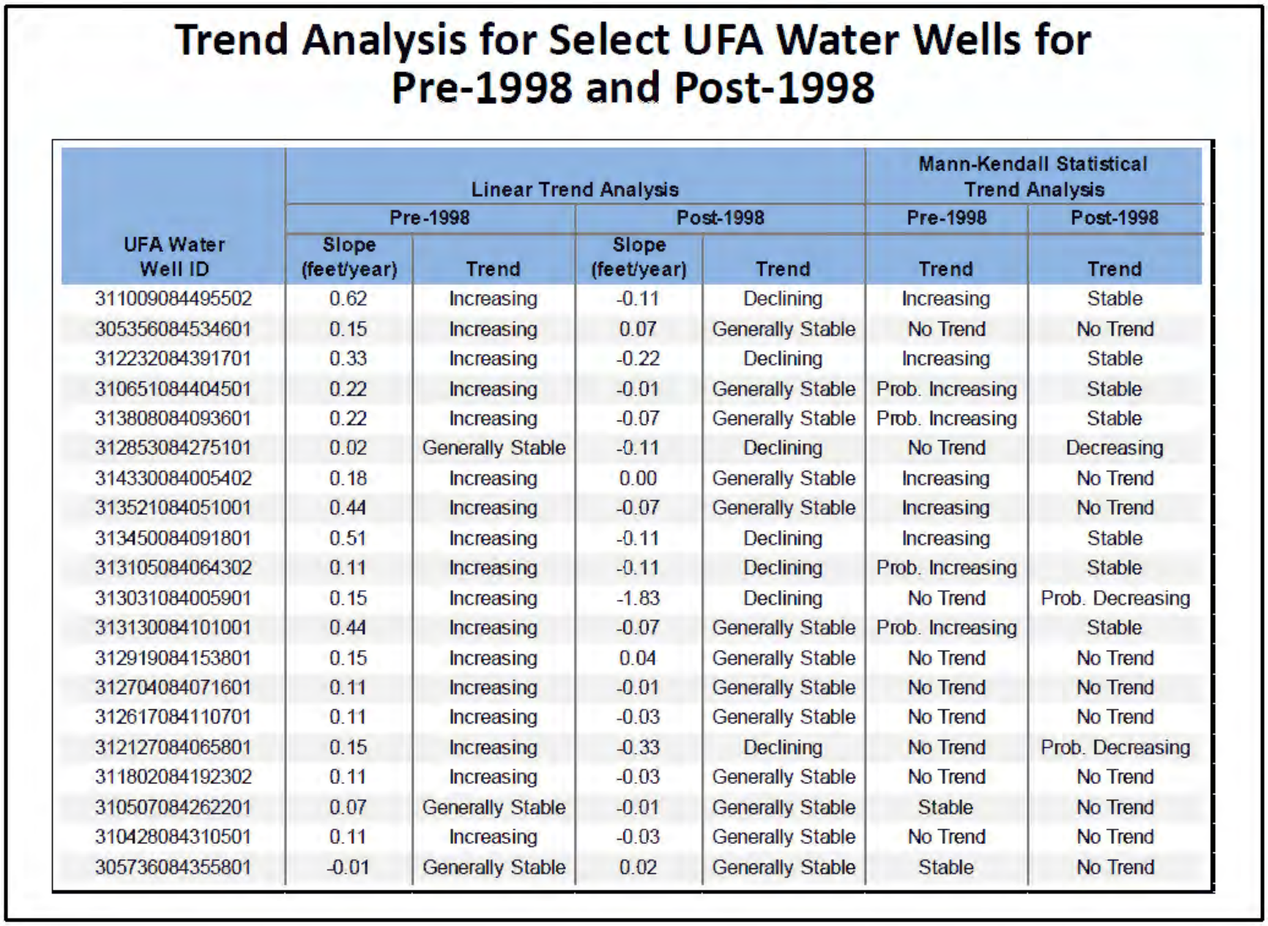
[5] Dr. Langseth testified that during recent years, the number of irrigated acres has been relatively stable (from 1999 to 2012). Dr. Flewelling's estimated irrigated acres and total irrigation has been generally stable since the last 1900s. *See* Flewelling Report, at 9 (Fig. 2.4) and 18 (Fig. 2.12).

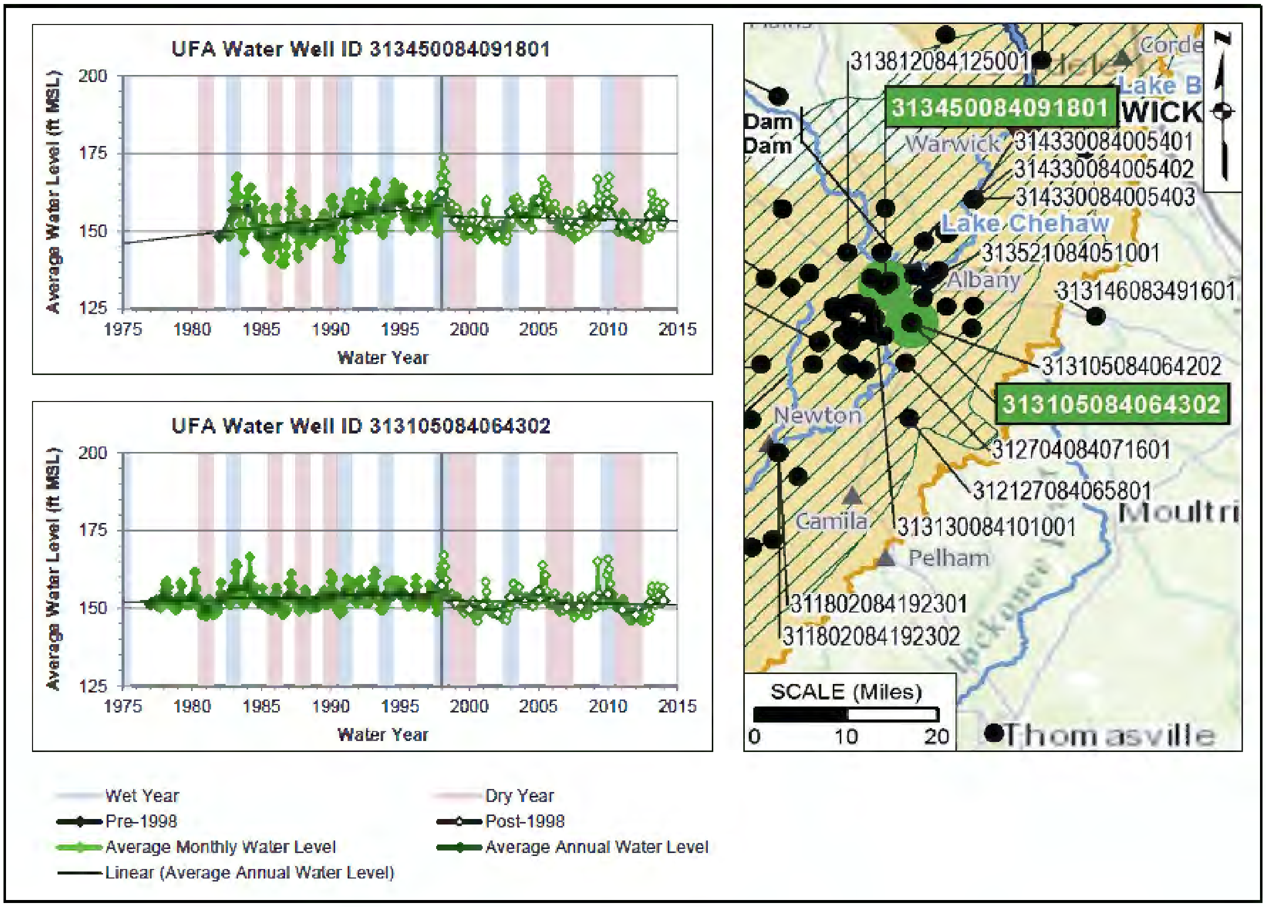


Trend Analysis for Select UFA Water Wells for Pre-1998 and Post-1998

UFA Water Well ID	Linear Trend Analysis				Mann-Kendall Statistical Trend Analysis	
	Pre-1998		Post-1998		Pre-1998	Post-1998
	Slope (feet/year)	Trend	Slope (feet/year)	Trend	Trend	Trend
311009084495502	0.62	Increasing	-0.11	Declining	Increasing	Stable
305356084534601	0.15	Increasing	0.07	Generally Stable	No Trend	No Trend
312232084391701	0.33	Increasing	-0.22	Declining	Increasing	Stable
310651084404501	0.22	Increasing	-0.01	Generally Stable	Prob. Increasing	Stable
313808084093601	0.22	Increasing	-0.07	Generally Stable	Prob. Increasing	Stable
312853084275101	0.02	Generally Stable	-0.11	Declining	No Trend	Decreasing
314330084005402	0.18	Increasing	0.00	Generally Stable	Increasing	No Trend
313521084051001	0.44	Increasing	-0.07	Generally Stable	Increasing	No Trend
313450084091801	0.51	Increasing	-0.11	Declining	Increasing	Stable
313105084064302	0.11	Increasing	-0.11	Declining	Prob. Increasing	Stable
313031084005901	0.15	Increasing	-1.83	Declining	No Trend	Prob. Decreasing
313130084101001	0.44	Increasing	-0.07	Generally Stable	Prob. Increasing	Stable
312919084153801	0.15	Increasing	0.04	Generally Stable	No Trend	No Trend
312704084071601	0.11	Increasing	-0.01	Generally Stable	No Trend	No Trend
312617084110701	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
312127084065801	0.15	Increasing	-0.33	Declining	No Trend	Prob. Decreasing
311802084192302	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
310507084262201	0.07	Generally Stable	-0.01	Generally Stable	Stable	No Trend
310428084310501	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
305736084355801	-0.01	Generally Stable	0.02	Generally Stable	Stable	No Trend

Panday Demo. 40 — Shows trend analysis for select UFA water wells for pre-1998 and post-1998. Data was obtained from the USGS (JX-128). Groundwater level hydrographs are included with the Panday Demo. 40 attached to this testimony.

123. When I look at just groundwater trends from 1970 to 1998, ***none*** of the wells show a decreasing trend. This is consistent under both my linear and Mann-Kendall analyses. This suggests that the significant growth in agricultural irrigation pumping from the UFA from 1970 to 1998 did not have a significant impact on groundwater levels in the UFA. An example of this trend is shown in Panday Demo. 41 below, which shows pre-1998 and post-1998 groundwater trends for two UFA monitoring wells in the Lower Flint River Basin.



Panday Demo. 41 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).

124. Dr. Hornberger testified that *"Agricultural pumping in Georgia has lowered the groundwater level of the Upper Floridan Aquifer by about four feet over several decades."* (Direct Testimony of G. Hornberger, ¶ 3d). This is false and is completely unsupported by analysis. Florida's experts have conducted a similar linear trend analysis of groundwater level data split into pre- and post-1992 values. Florida experts note declines in the trends for the post-1992 conditions, but none have conducted any analysis whatsoever to analyze the cause of those declines. A close look at the post-1992 time period indicates that it starts with 6 years of wet and normal precipitation, followed by periods with 3 severe multi-year droughts. Starting with a wet period and finishing off with dry years will of course result in a declining trend—this trend is obviously caused by the weather. This also indicates that selectively splitting up a long period of record can produce subjective and ambiguous results. But even in this analysis, it is apparent that water levels were not declining from the mid-1970s through 1992, even though there were

significant increases in pumping within Georgia during that time period. In short, Florida's claim that Georgia's groundwater pumping has decreased aquifer levels by a specific amount is unsubstantiated and wholly unsupported.

D. Modeling of a hypothetical lowering of water levels throughout the UFA shows a minimal impact on basin-wide streamflow.

125. Although Dr. Langseth offers a number of opinions about groundwater levels in Georgia, neither he nor any other Florida expert made any effort during the discovery period to show how groundwater levels in Georgia impact flows into Florida.

126. By contrast, I modeled the impact on streamflow from a hypothetical decrease in groundwater levels using the Jones and Torak (2006) MODFE model (whether there is a basin-wide decline or not, and regardless of the cause) and included those results in my expert report. Specifically, I quantified the effect of a hypothetical lowering of long-term basin-wide groundwater levels by 2 feet, and found the impact on streamflow to be between 39 and 217.5 cfs. Thus, even if there were to be a basin-wide 2 foot decline in water levels, the impact would be minimal–the largest impact being 4.4% of the minimum flow at Woodruff Dam of 5,000 cfs (i.e., almost 23 time smaller).

127. Dr. Langseth now includes a new opinion in his written direct testimony on October 14, 2016 that every foot of groundwater decline results in 340 cfs less discharge to streams. (Direct Testimony of D. Langseth, ¶ 2D and 44). New material that he relied upon in support of this analysis was provided to me as recently as October 23, 2016. Given the limited time I have had to review this new analysis and materials, I reserve my right to supplement or modify my testimony related to this topic after I have had more time to review.

128. In his written direct testimony, Dr. Langseth does not explain how *"groundwater-level data and baseflow estimation methods"* (Direct Testimony of D. Langseth, ¶ 44), provide this number and I was only recently provided (on October 23, 2016) any supplemental production or information that would allow me to analyze his methods. PART is a baseflow separation code, freely available from USGS and is one of several such codes available to separate a streamflow hydrograph into a baseflow portion and a surface-runoff portion. Each

code may use a different method of computing this separation; however, the hydrograph analysis uses streamflow at a gage as its only input.

129. If the objective of a study is to separate a streamflow signal at a river gage into its baseflow and runoff components, you would use a baseflow separation code like PART. However, this provides no information about the impact to baseflow from changes in water levels or pumping. In other words, it cannot tell how much the baseflow was ***reduced*** as a result of groundwater level declines or of a certain amount of pumping at any location. There aren't even inputs for water levels, groundwater pumping, or withdrawal locations in PART.

130. However, if the objective of a study is to evaluate the ***impact of groundwater pumping on groundwater contribution to streamflow***, you should use a groundwater flow model like MODFE, which simulates all the impacts and complex interactions between pumping, groundwater levels and baseflow reduction. This is what I have done.

131. The supporting analysis material provided to me on October 23, 2016 suggests that Dr. Langseth used the PART code to separate out baseflow from the streamflow signal and then correlated that to groundwater levels that he averaged at all gages. As I have noted earlier, there is no basin-wide trend in water levels since the 1970s with different wells showing different signatures. It is improper to use an unweighted average of water levels to represent basin-wide groundwater conditions as Dr. Langseth appears to have done; especially when the wells do not behave in a similar manner. Finally, he does not distinguish between the ***causes*** for declines in baseflow or water levels. I have evaluated this (see ¶ 113 through 118 above) and have noted that water levels did not decline in the pre-1998 time period when the largest pumping increases occurred in the UFA–instead, they were lower in the post-1998 time period which is coincident with more severe, longer duration and more frequent droughts.

X. FLORIDA FOCUSES ON LOCAL ISSUES THAT HAVE LITTLE SIGNIFICANCE ON STATE-LINE FLOWS INTO FLORIDA

132. In claiming that Georgia is pumping beyond the “sustainable yield” of the UFA, Florida has focused on local issues that have a negligible impact on the overall flow from Georgia into Florida. Specifically, Florida has consistently raised two issues throughout the case: i) a study by Georgia EPD on sustainable yield for the UFA; and ii) an evaluation of flow

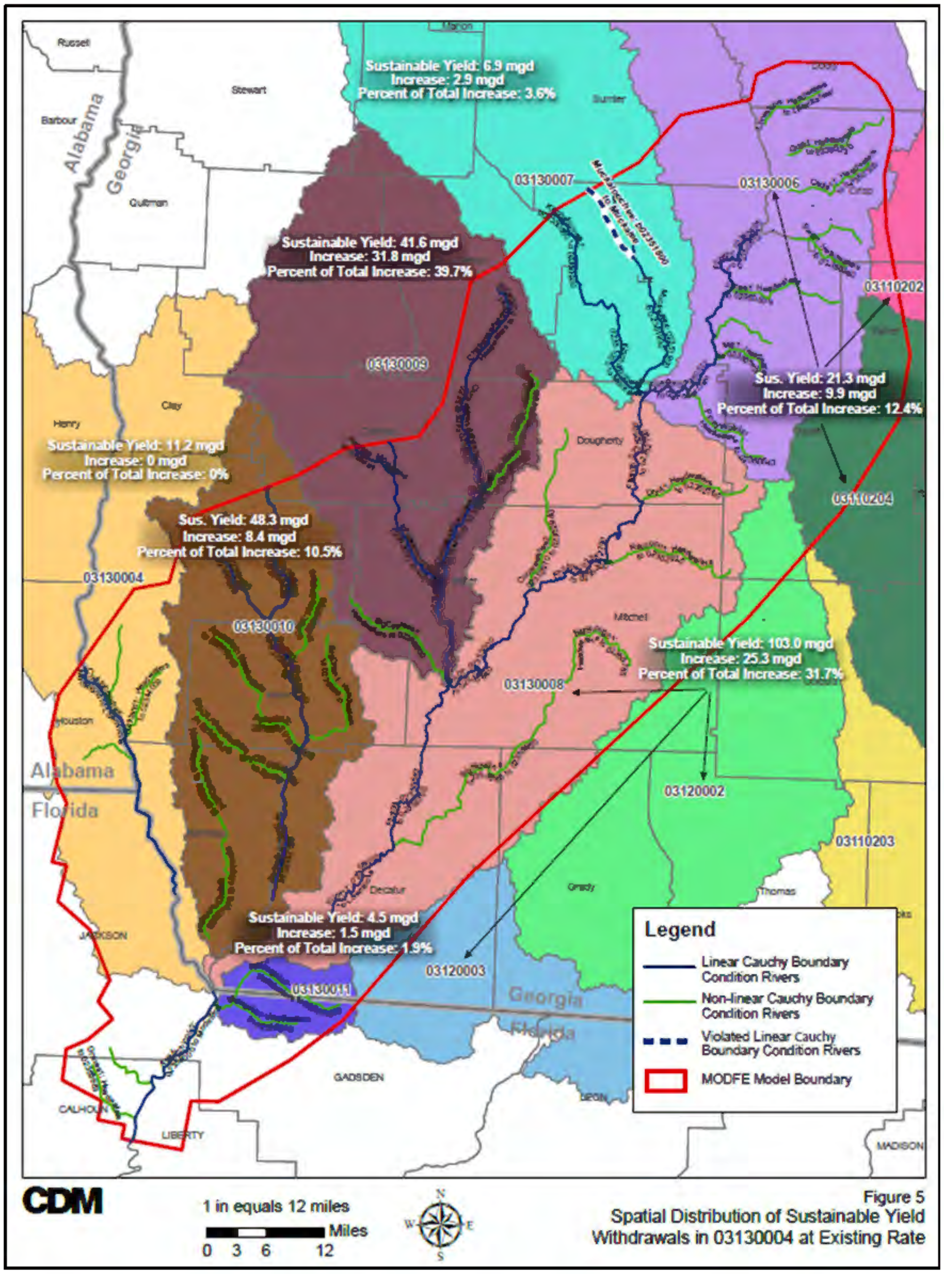
in Spring Creek in Georgia. Other issues that Florida raises include flow at Radium Springs and the impact of errors or uncertainties in agricultural irrigation pumping. Each of these issues similarly has minimal impact on state-line flows into Florida.

A. The UFA "sustainable yield" limit has a negligible impact on flow of the rivers into Florida.

133. Florida claims that a study conducted for Georgia's Statewide Water Plan supports its conclusion that groundwater pumping from the UFA is not sustainable and therefore detrimental to flow of the Chattahoochee and Flint Rivers into Florida. *See* Expert Report of D. Langseth. When placed in the proper context, this study is minimally relevant to the issues in this case. The Resource Assessment referenced by Florida was conducted for the first round of regional water planning under Georgia's State Water Plan, which was the start of a comprehensive and on-going planning effort. The Resource Assessment evaluation was designed as a high-level screening tool to identify issues with availability of water from specific resources. The study was not designed to evaluate the impact of water use on flow of the Chattahoochee and Flint Rivers into Florida, and consequently did not do so.

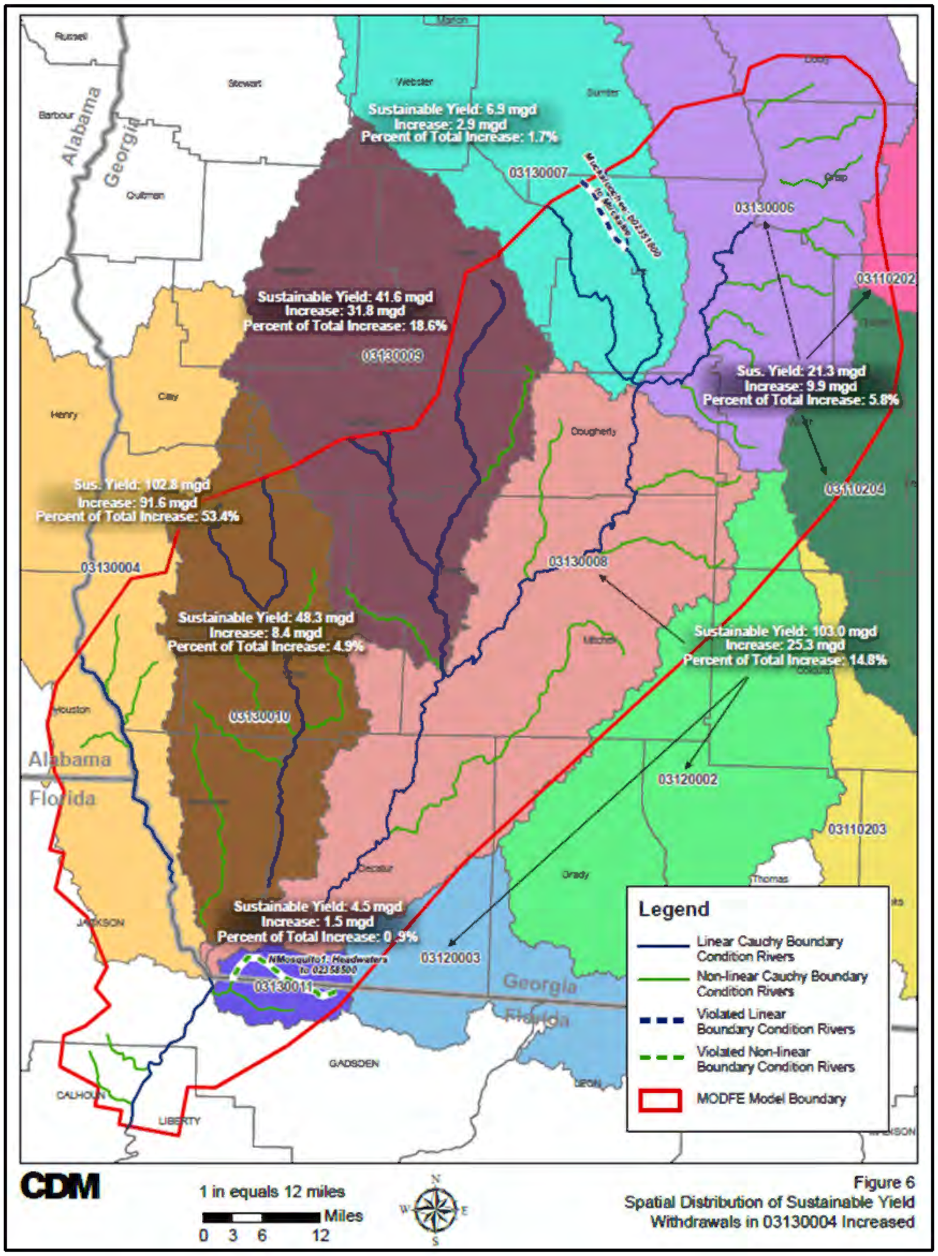
134. Instead, the sustainable yield study identified localized impacts to streamflow caused by groundwater pumping so that subsequent analysis and planning could be directed toward those issues. Using the steady-state model of October 1999 conditions developed by Jones and Torak (2006), the sustainable yield criterion was "triggered" if pumping caused a modeled reduction in streamflow equivalent to 40% of the total groundwater flow to the stream in ***any*** tributary (CDM, 2011). This trigger was met in two different scenarios.

135. As Panday Demo. 42 below shows, the ***only*** section of the entire ACF River Basin that triggered the "sustainable yield" criterion under this scenario of the CDM study, was in an upstream section of Muckaloochee Creek in Georgia, which is a small upstream tributary to the Flint River located about 100 miles from the state line. Moreover, that small tributary only received 1.7 cfs of flow from groundwater triggering the sustainable yield criterion with ***a reduction of less than 0.7 cfs*** (40% of non-pumping streamflow). As a result, the "sustainable yield" trigger at Muckaloochee Creek, which may have local significance, has virtually no impact at all on streamflows at the state line.



Panday Demo. 42 — Technical Memorandum on Dougherty Plain Sustainable Yield Groundwater Model (CDM 2012 Figure. 5) (JX-057).

136. In a second scenario, the streamflow criterion was triggered at an additional location—Mosquito Creek, located near the Georgia-Florida state boundary (see Panday Demo. 43 below). Groundwater flow into Mosquito Creek was 0.07 cfs for non-pumping conditions; thus, any reduction in streamflow would have no bearing on net flow into Florida.



Panday Demo. 43 — Technical Memorandum on Dougherty Plain Sustainable Yield Groundwater Model (CDM 2012 Figure. 6) (JX-057).

B. Concerns raised by Florida regarding Spring Creek have minimal influence on state-line flows.

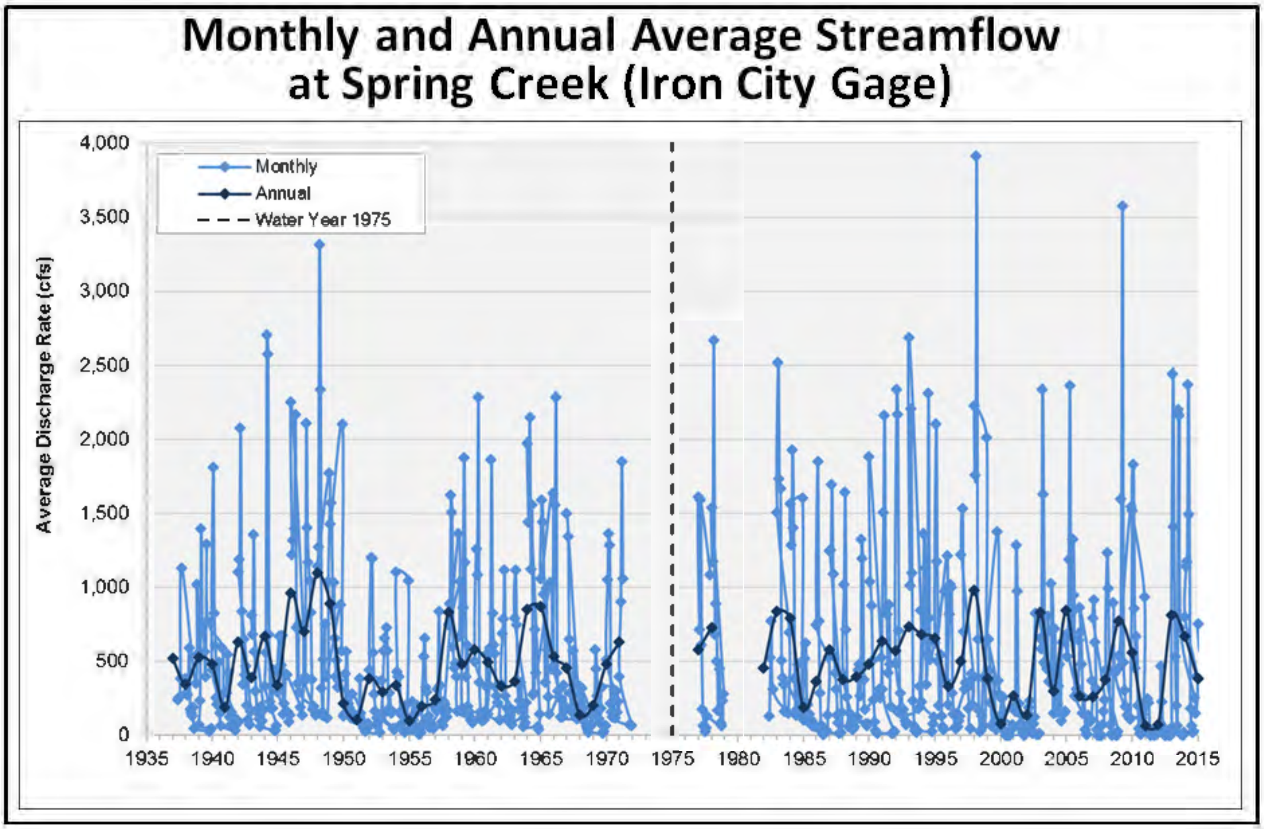
137. Dr. Hornberger and other Florida experts have also highlighted that the Iron City Gage (USGS Station ID 02357000) on Spring Creek had some measurable flow from 1938 to

1980, but that since 1980 has had “no flow” on numerous days (Direct Testimony of G. Hornberger, ¶ 56). However Florida’s experts do not quantify the impact from pumping, versus impacts related to drought conditions, nor does any expert analyze the impact of Spring Creek on state-line flows into Florida. First, Dr. Hornberger and Florida’s experts only consider the Iron City Gage on Spring Creek and ignore a downstream gage that has always shown flow. Second, they ignore the relatively small impact Spring Creek has on state-line flows. Third, they fail to consider that very low flows have occurred at Spring Creek during droughts, even in the pre-irrigation flow record. Finally, they have conducted no modeling analysis to determine exactly what impact—if any—groundwater pumping in the UFA has on Spring Creek.

138. Spring Creek at the Iron City Gage has a drainage area of 490 square miles and no-flow conditions observed at that gage are a local phenomenon. The next downstream gage is on Spring Creek near Reynoldsville, Georgia (USGS Station ID 02357150; with a drainage area of 571 square miles) (JX-128). This gage has never measured no-flow conditions, even during the recent severe drought years of 2007, 2011, and 2012. Thus, Spring Creek is a gaining reach and has never entirely stopped flowing during the period of record.

139. I have evaluated Spring Creek’s influence on state-line flows into Florida and find them to be negligible. During dry years, Spring Creek contributes an average of 200 cfs to Lake Seminole (about 2% of the average dry-year flow from Woodruff Dam into Florida). For dry months, flow at Spring Creek is just a fraction of a percent of the minimum monthly flows from Woodruff Dam into Florida.

140. Dr. Hornberger admits that pre-1980 flows at the Iron City Gage have been very low (Direct Testimony of G. Hornberger, ¶ 56). From 1938 through 1980, monthly minimum flows at the Iron City Gage have been between 10 and 20 cfs on many occasions during past droughts, as noted on Panday Demo. 44 below (reflecting data from JX-128). Thus, “no-flow” conditions at the Iron City Gage in recent droughts, as compared to 10 or 20 cfs of pre-1980 droughts, have little to no impact on streamflow from Woodruff Dam into Florida.



Panday Demo. 44 — Panday Expert Report (GX-0873), 20 May 2016, Fig. F-5. Data was obtained from the USGS (JX-128).

141. Finally, no Florida expert has conducted any modeling to isolate the impact of pumping to baseflow at the Iron City Gage, versus impact from weather. My modeling results[6] show the impact of groundwater pumping from the UFA to streamflow at the Iron City Gage, indicating that all groundwater pumping from the UFA has a maximum impact of just over 30 cfs (July 2011 Dry Scenario, as noted in Panday Demo. 45 below). This quantity is negligible (167 times less) in comparison to even the minimum state-line flows of 5,000 cfs into Florida.

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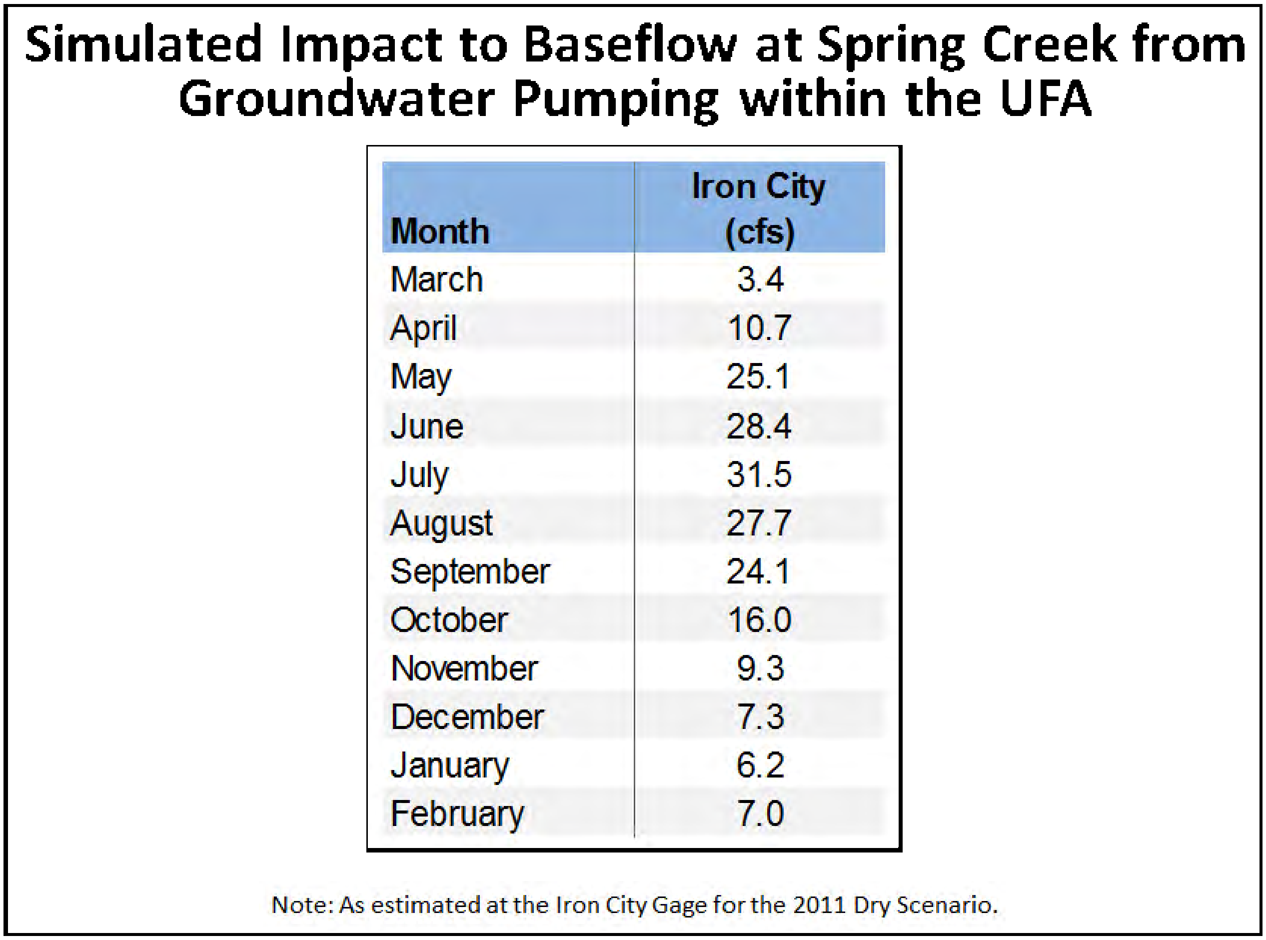
[6] GX-0951 is a true and accurate copy of my modeling results separated out by sub-basins.



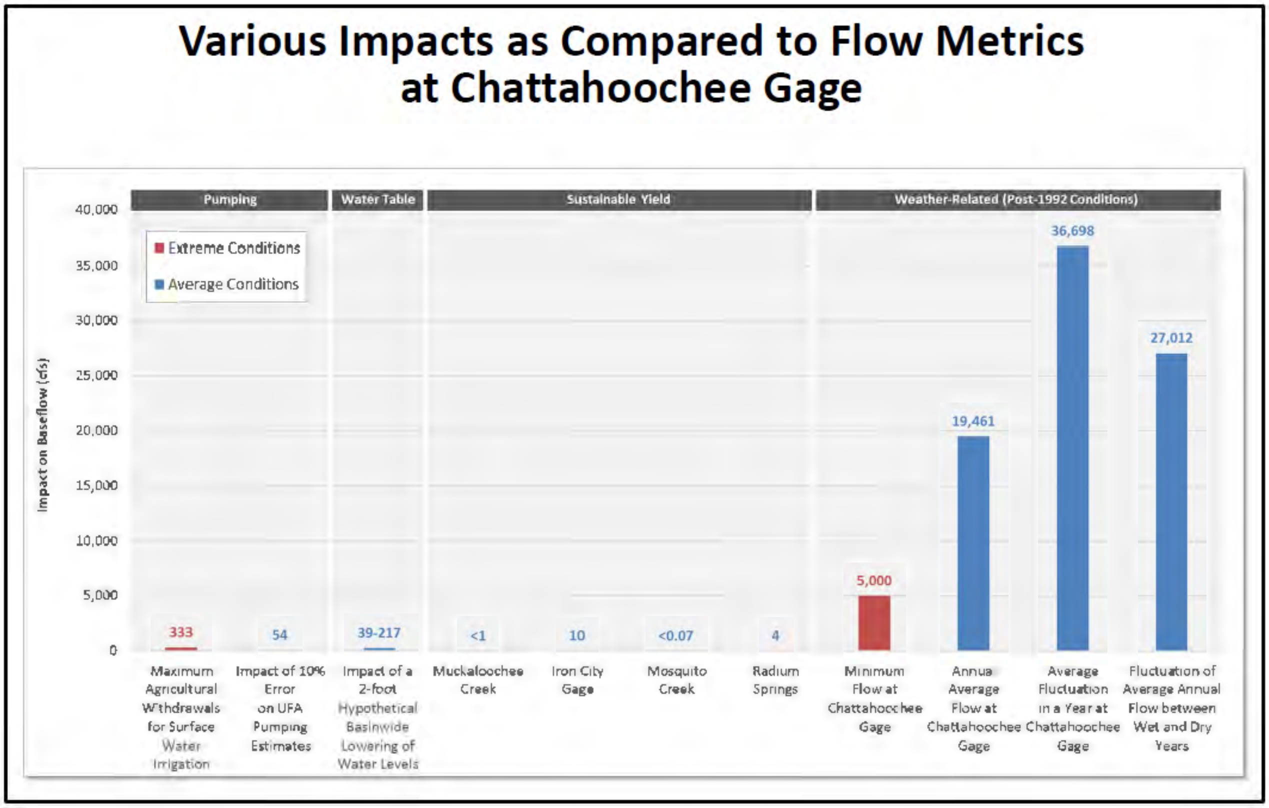
Simulated Impact to Baseflow at Spring Creek from Groundwater Pumping within the UFA

Month	Iron City (cfs)
March	3.4
April	10.7
May	25.1
June	28.4
July	31.5
August	27.7
September	24.1
October	16.0
November	9.3
December	7.3
January	6.2
February	7.0

Note: As estimated at the Iron City Gage for the 2011 Dry Scenario.

Panday Demo. 45 — Panday Expert Report, 20 May 2016, Table E-4 (GX-0951) and (GX-0873).

142. Panday Demo. 46 below shows the impact of these and other issues raised by Florida, against some of the flow metrics at the Chattahoochee Gage that measure the low flow levels, the annual fluctuation in flow, and the variation in flow related to wet and dry weather conditions. It is noted that all of these issues have a negligible impact in comparison to flows governed by weather-related conditions in the ACF River Basin.



Panday Demo. 46 — Comparison of impacts identified by Florida with flow metrics at the Chattahoochee gage. Gage data was obtained from the USGS (JX-128).

CONCLUSION

143. My modeling shows that Georgia's groundwater pumping has little impact on basin-wide streamflow. Streamflow from Georgia into Florida is dominated by weather patterns. All agricultural irrigation and M&I pumping from the UFA in Georgia have a minimal impact when compared to observed flows into Florida; a reduction of pumping to 1992 conditions has an even lesser impact. A hypothetical lowering of the water table throughout the UFA also has a negligible impact when compared to observed flows into Florida. Finally, the local issues raised by Florida have virtually no impact when compared with state-line flows into Florida.

LIST OF SOURCES

JX-017 is a true and accurate copy of Ag Water Pumping Project Report 52, Final Report by James Hook, Kerry Harrison, Gerrit Hoogenboom, and Daniel Thomas. This document contains data regularly relied upon by experts in my field, and I relied on this document to form my opinions.

JX-018 is a true and accurate copy of Jones, L.E., and L.J. Torak. 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, U.S. Geological Survey Scientific Investigations Report 2006-5234. This is a study published by USGS. Experts in my field recognize that USGS a reliable authority on groundwater and surface water. I rely on JX-018 and related MODFE model when forming my opinions in this testimony.

JX-043 is a true and accurate copy of Surface & Groundwater Water Demand by Local Drainage Areas (LDA's) - NESPAL; Hook, J.E. (2010). This document contains data related to wetted acreage, this type of information is regularly relied on by experts in my field, and I relied on this document to form my opinions.

JX-057 is a true and accurate copy of Technical Memorandum on Dougherty Plain Sustainable Yield Groundwater Model by CDM. This document contains data and modeling results regularly relied on by experts in my field and I relied on this document to form my opinions.

JX-076 is a true and accurate copy of Technical Memorandum — Claiborne and Cretaceous Aquifers by CDM. This document contains data and modeling results regularly relied on by experts in my field and I relied on this document to form my opinions.

JX-128 refers to data obtained from USGS related to surface water and groundwater. Experts in my field recognize that USGS is a reliable source for this data and I relied on this data when forming my opinions in this case.

JX-0143 is a true and accurate copy of Georgia's Agricultural Metering database. This document contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0080 is a true and accurate copy of a memo titled *"Irrigation depths for water use planning in the Lower Flint River Basin"* by Dr. James E. Hook (April 13, 2005). This document contains state-wide irrigation trends. Dr. Hook is a reliable authority on this topic. This document contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0090 is a true and accurate copy of a study Torak, L.J., and J.A. Painter. Geohydrology of the Lower Apalachicola-Chattahoochee- Flint River Basin, Southwestern Georgia, Northwestern Florida, and Southeastern Alabama, U.S. Geological Survey Scientific Investigations Report 2006-5070. This is a study published by USGS. Experts in my field recognize that USGS a reliable authority on groundwater and surface water. I rely on this document when forming my opinions in this testimony.

GX-0267 is a true and accurate copy of Zeng, W. Agricultural water use and its surface water effects in the Flint and Lower Chattahoochee River Basins, Memorandum to file. (April 3, 2009). This document contains data and modeling results regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0873 is a true and accurate copy of the expert report I submitted in this case.

GX-0882 is a true and accurate copy of the Errata for expert report of Sorab Panday that I wrote in connection with this case.

GX-0883 is a true and accurate copy of Memo from Sorab Panday to Dr. Phillip Bedient re Review of Dr. David Langseth's Memo to Dr. George Hornberger on 28 June 2016 titled *"Dr. Panday Water Budget Evaluations"* that I wrote in connection with this case.

GX-0903 is a true and accurate copy of "20130319-Ag-GW-Rate-Pattern-2008-2012.xls" a document that I received from Georgia EPD. This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0918 is a true and accurate copy of “2009_Water_Usage_GSWCC.xls” which contains metered data. This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0925 is a true and accurate copy of “2012 Usage for EPD.xlsx”. This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0929 is a true and accurate copy of “2013_Water_Usage_EPD.xlsx” This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0951 is a true and accurate copy of 4198_APP E_Tables E-2 to E-5_Back-up.xlsx which contains results of my modeling.

GX-0952 is a true and accurate copy of HookvsLULC.xlsx which I used in my analysis showing the relative show the relative amounts of pumping within Georgia compared with Florida and Alabama. This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0954 is a true and accurate copy of 4198_MODFE_InputFiles_IrrigationPumping_28Jan2016.xlsx which includes irrigation input files that I used in my modeling. This file contains data regularly relied on by experts in my field and I relied on this document to form my opinions.

GX-0955 is a true and accurate copy of “5-1 - 5-3_4198_MainText_Tabs_5-1 to 5-3.xlsx” which includes my modeling results and which show the relative impact of pumping within Georgia compared with Florida and Alabama on baseflow reduction within the model domain. These results regularly relied on by experts in my field and I relied on the results reflected in this document to form my opinions.

GX-1026 is a true and accurate copy of my Curriculum Vitae.

GA-1156 is a true and accurate copy of precipitation data that I obtained from NOAA. Experts in my field recognize that the NOAA a reliable source for precipitation data. I rely on this data when forming my opinions in this testimony.

GX-1214 is a true and accurate copy of census data that I obtained from the U.S. Census Bureau. Experts in my field recognize that the U.S. Census Bureau a reliable source for population data. I rely on this data when forming my opinions in this testimony.

GX-1259 is a true and accurate copy of irrigated acreage data that I received from Georgia EPD. This data is regularly relied on in my field, and I relied on this data when forming my opinions.

No. 142, Original

In The
Supreme Court of the United States

STATE OF FLORIDA,

Plaintiff,

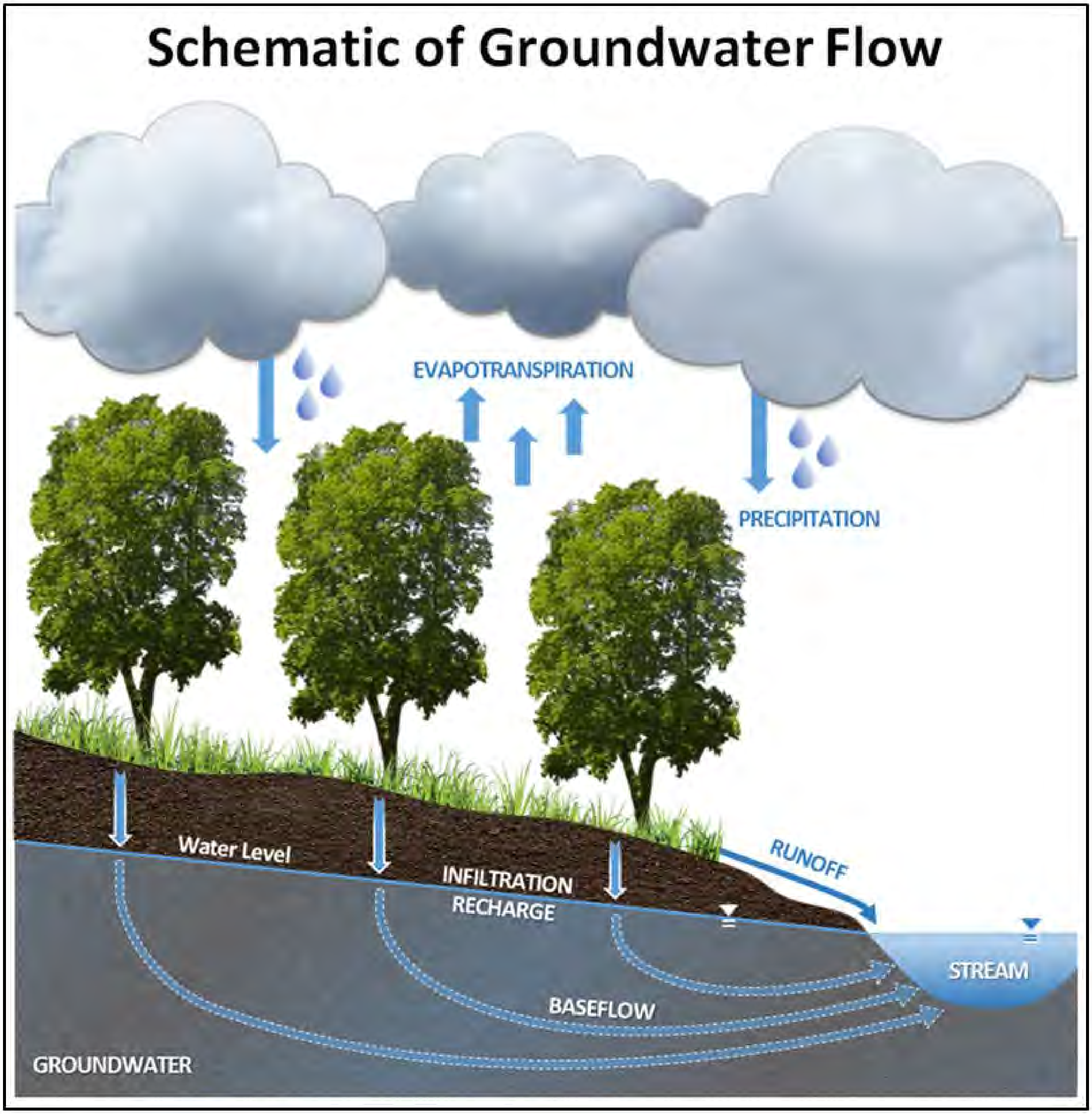
v.

STATE OF GEORGIA,

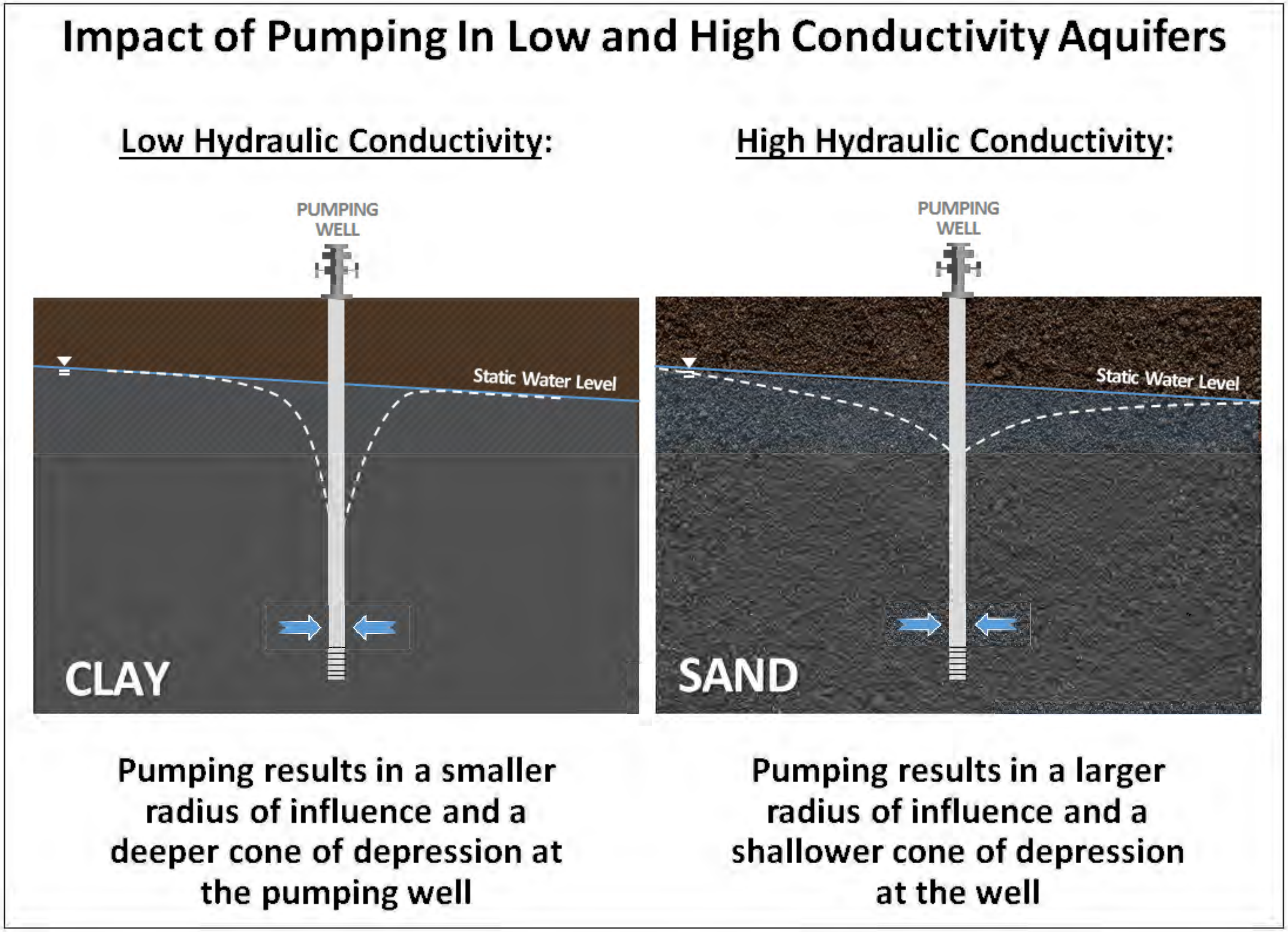
Defendant.

DEMONSTRATIVES FROM THE DIRECT TESTIMONY OF SORAB PANDAY, PH.D.

October 26, 2016



Panday Demo. 1 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-1.



Impact of Pumping In Low and High Conductivity Aquifers

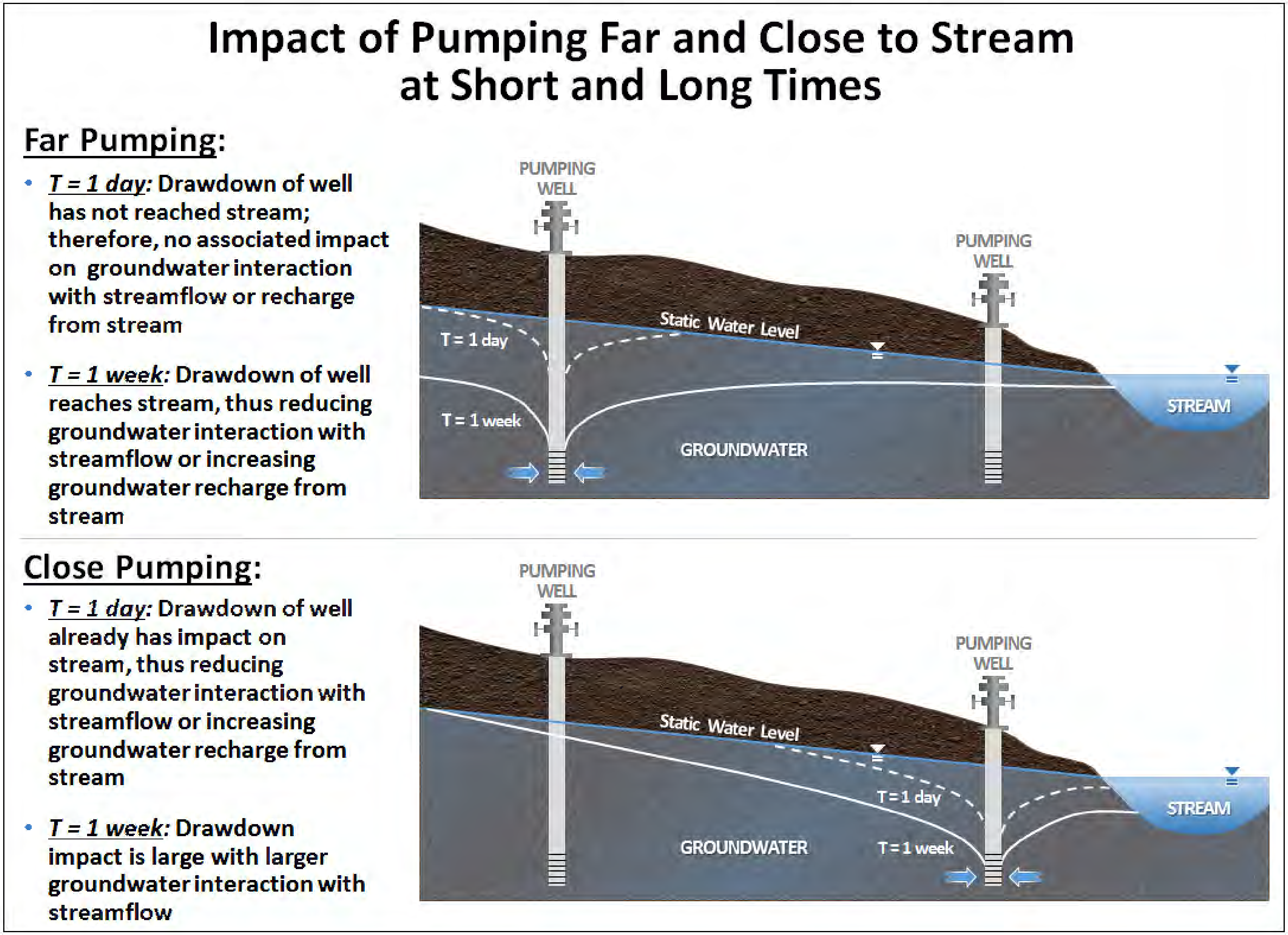
Low Hydraulic Conductivity:

High Hydraulic Conductivity:

Pumping results in a smaller radius of influence and a deeper cone of depression at the pumping well

Pumping results in a larger radius of influence and a shallower cone of depression at the well

Panday Demo. 2 — Impact of Pumping in Low and High Conductivity Aquifers.



Impact of Pumping Far and Close to Stream at Short and Long Times

Far Pumping:

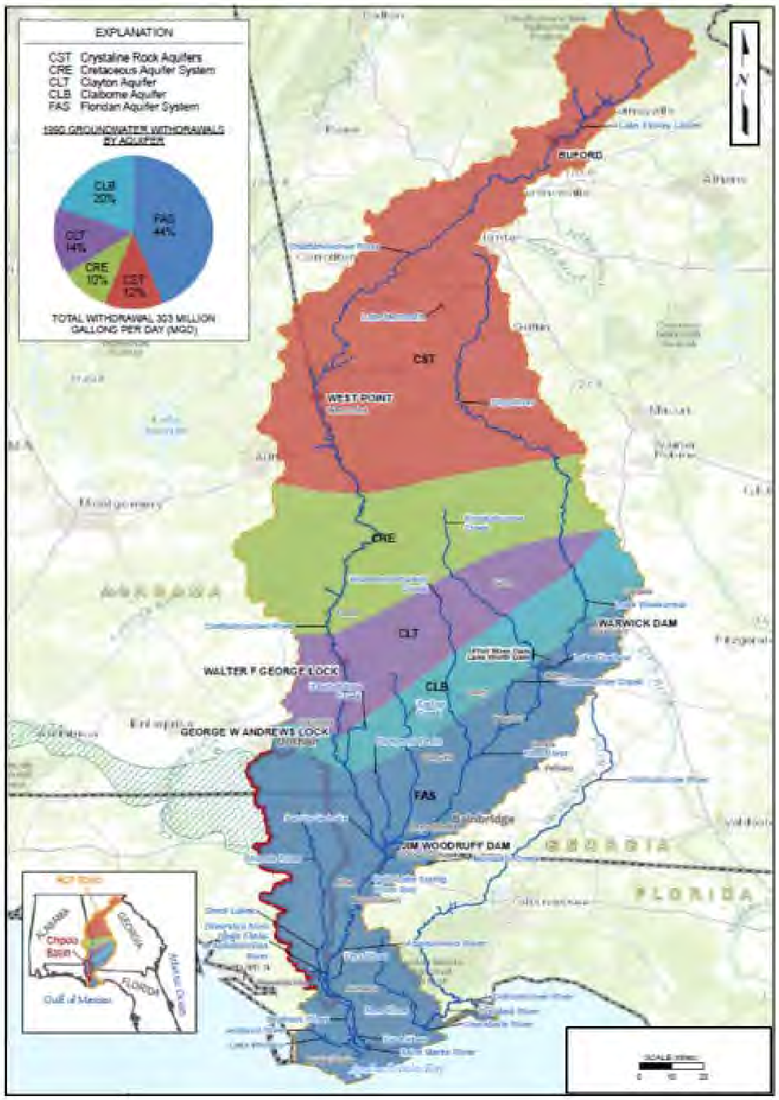
- ***T = 1 day:*** **Drawdown of well has not reached stream; therefore, no associated impact on groundwater interaction with streamflow or recharge from stream**
- ***T = 1 week:*** **Drawdown of well reaches stream, thus reducing groundwater interaction with streamflow or increasing groundwater recharge from stream**

Close Pumping:

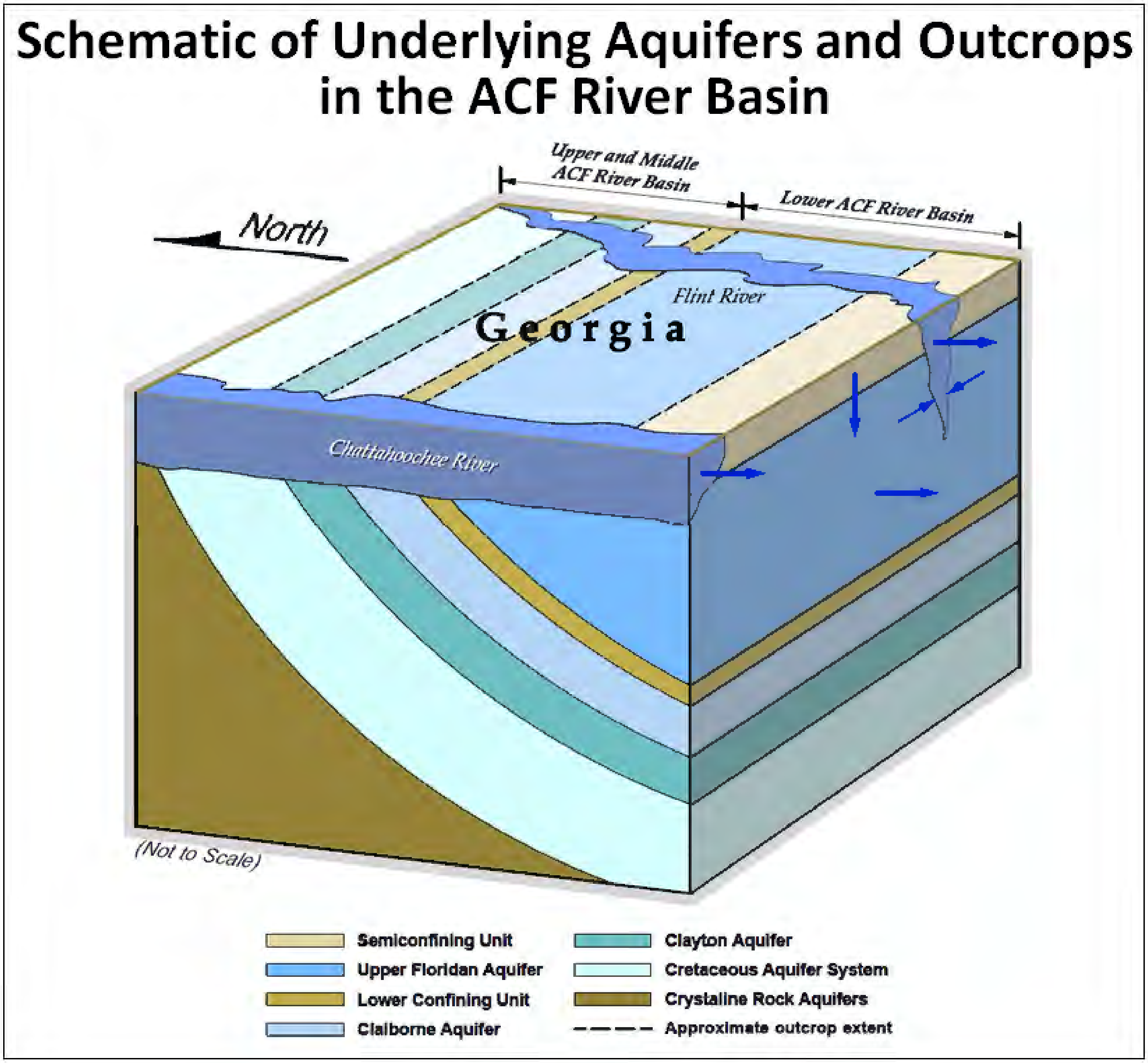
- ***T = 1 day:*** **Drawdown of well already has impact on stream, thus reducing groundwater interaction with streamflow or increasing groundwater recharge from stream**
- ***T = 1 week:*** **Drawdown impact is large with larger groundwater interaction with streamflow**

Panday Demo. 3 — Modified from Panday Expert Report, 20 May 2016, Figure 3-1.

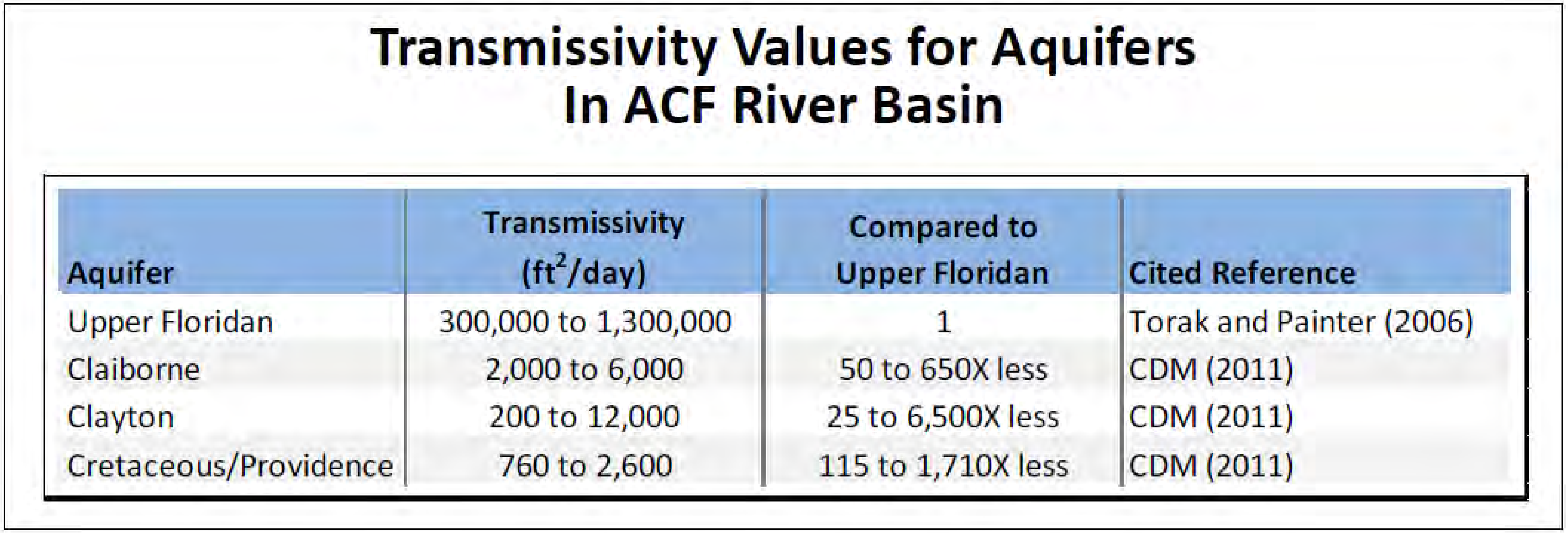
ACF River Basin Aquifers and Outcrop Areas



Panday Demo. 4 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. B-8.



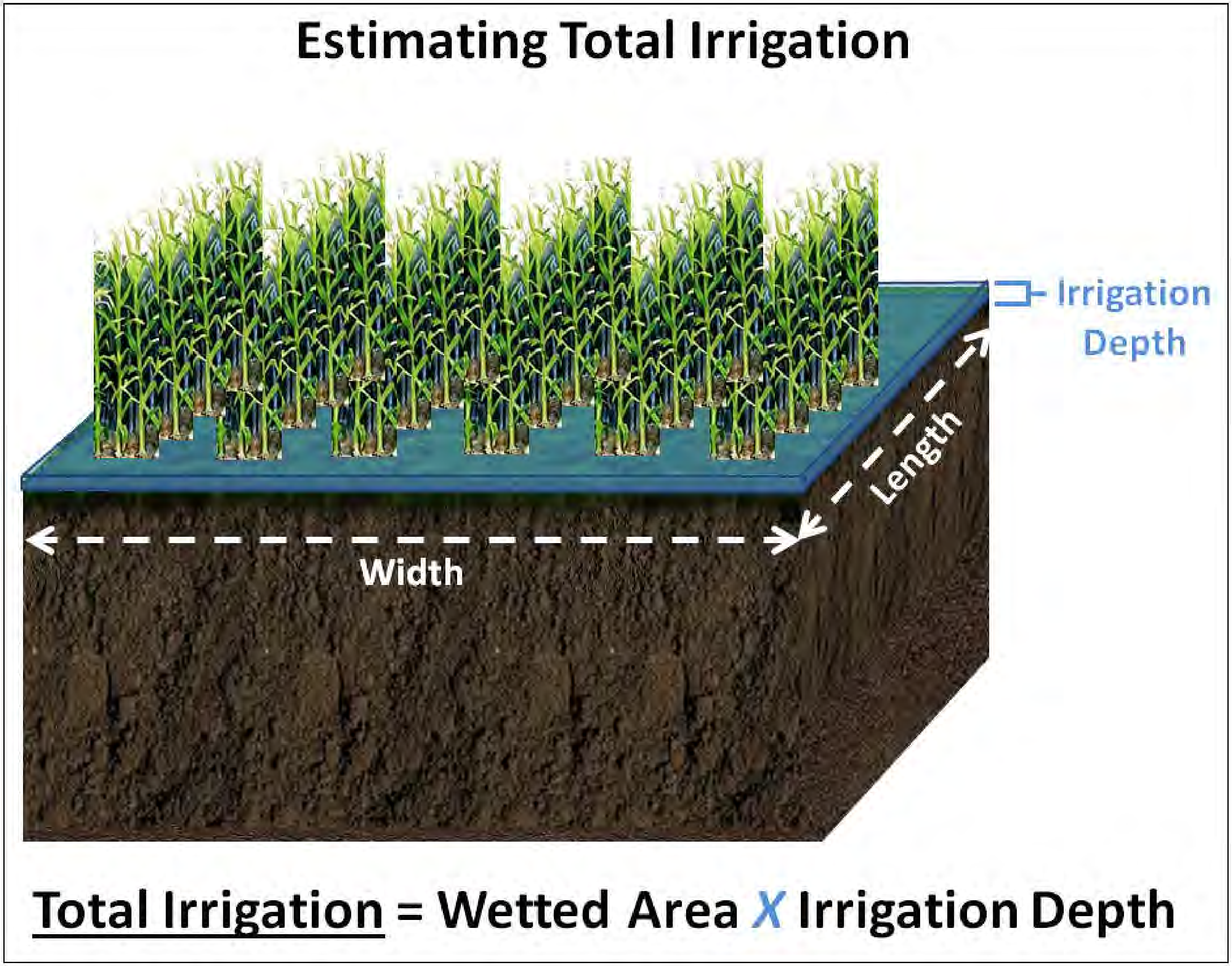
Panday Demo. 5 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.



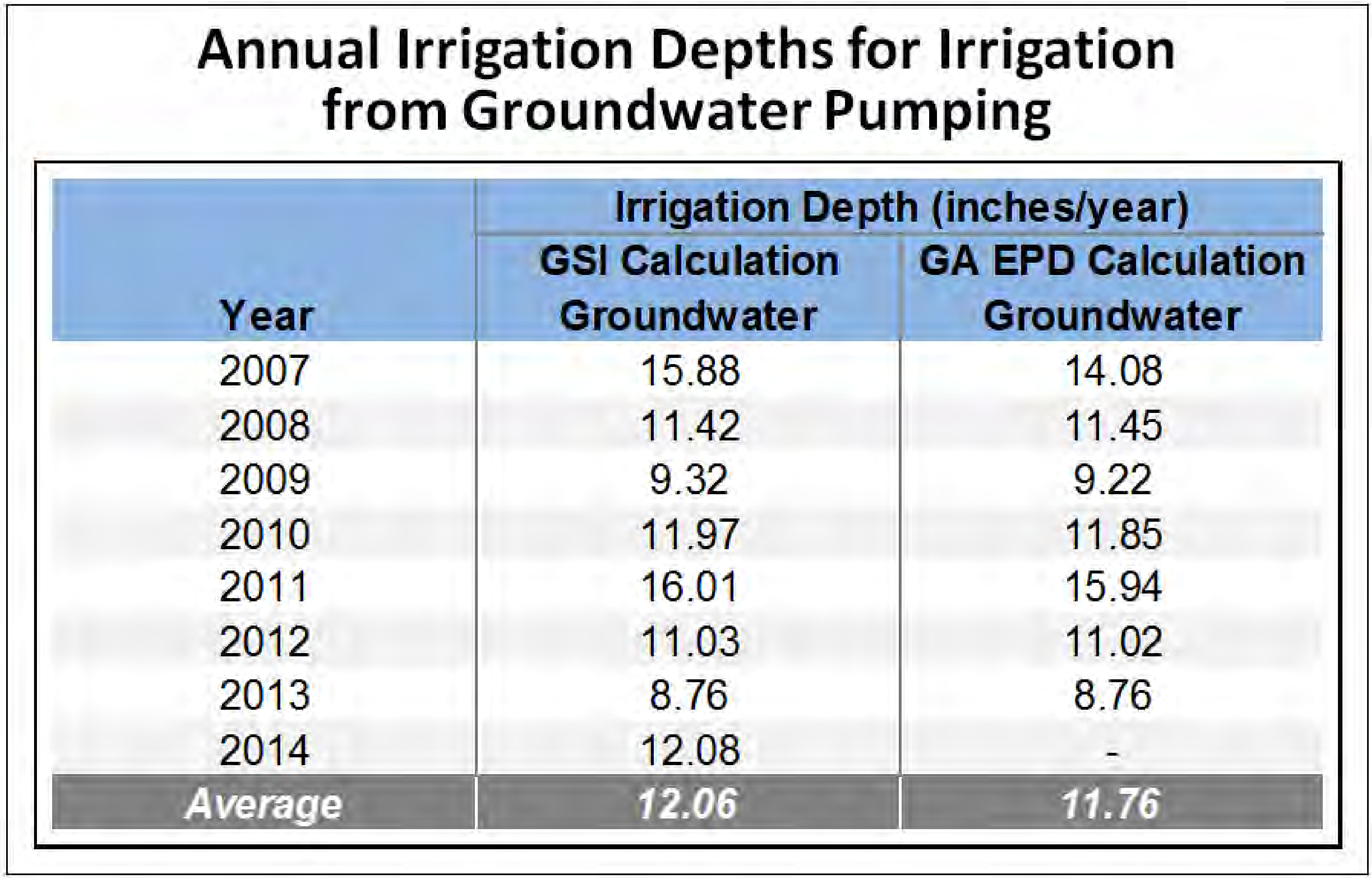
Transmissivity Values for Aquifers
In ACF River Basin

Aquifer	Transmissivity (ft^2/day)	Compared to Upper Floridan	Cited Reference
Upper Floridan	300,000 to 1,300,000	1	Torak and Painter (2006)
Claiborne	2,000 to 6,000	50 to 650X less	CDM (2011)
Clayton	200 to 12,000	25 to 6,500X less	CDM (2011)
Cretaceous/Providence	760 to 2,600	115 to 1,710X less	CDM (2011)

Panday Demo. 6 — Table of Transmissivity Values for Aquifers in the ACF River Basin (GX-0090, JX-076).



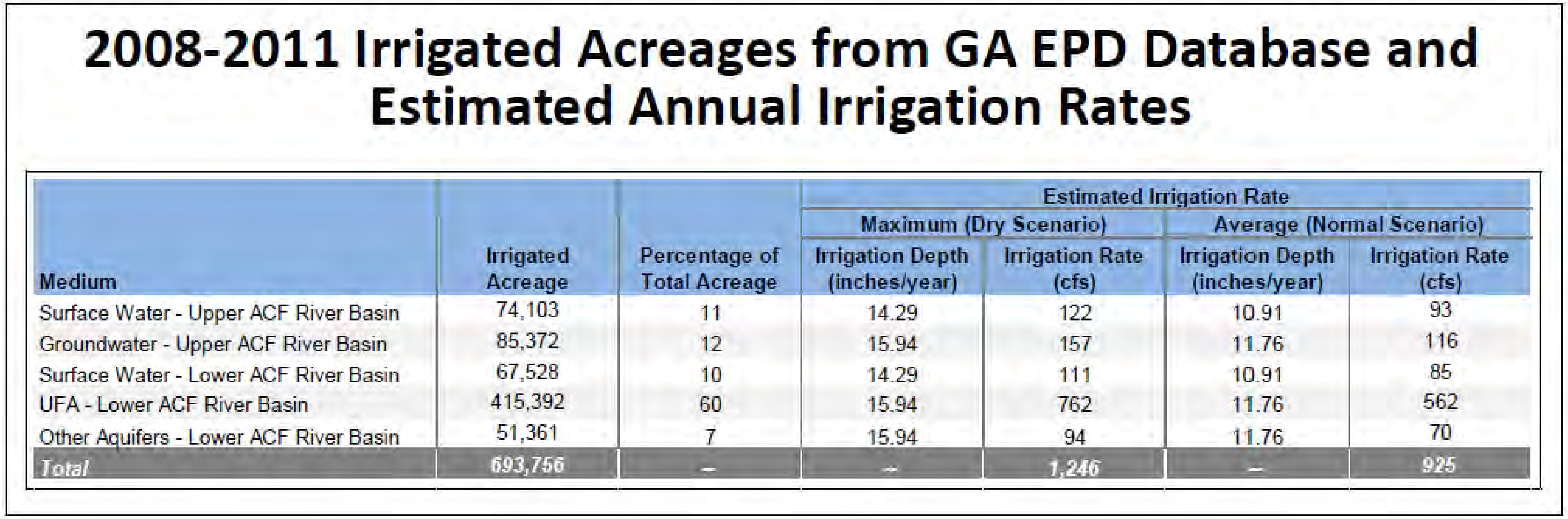
Panday Demo. 7 — Estimating Total Irrigation.



Annual Irrigation Depths for Irrigation from Groundwater Pumping

Year	Irrigation Depth (inches/year)	
	GSI Calculation Groundwater	GA EPD Calculation Groundwater
2007	15.88	14.08
2008	11.42	11.45
2009	9.32	9.22
2010	11.97	11.85
2011	16.01	15.94
2012	11.03	11.02
2013	8.76	8.76
2014	12.08	-
Average	***12.06***	***11.76***

Panday Demo. 8 — Panday Expert Report (GX-0873), 20 May 2016, Table C-3.



2008-2011 Irrigated Acreages from GA EPD Database and Estimated Annual Irrigation Rates

Medium	Irrigated Acreage	Percentage of Total Acreage	Estimated Irrigation Rate			
			Maximum (Dry Scenario)		Average (Normal Scenario)	
			Irrigation Depth (inches/year)	Irrigation Rate (cfs)	Irrigation Depth (inches/year)	Irrigation Rate (cfs)
Surface Water - Upper ACF River Basin	74,103	11	14.29	122	10.91	93
Groundwater - Upper ACF River Basin	85,372	12	15.94	157	11.76	116
Surface Water - Lower ACF River Basin	67,528	10	14.29	111	10.91	85
UFA - Lower ACF River Basin	415,392	60	15.94	762	11.76	562
Other Aquifers - Lower ACF River Basin	51,361	7	15.94	94	11.76	70
Total	*693,756*	–	–	*1,246*	–	*925*

Panday Demo. 9 — Panday Expert Report (GX-0873), 20 May 2016, Revised Table C-8.

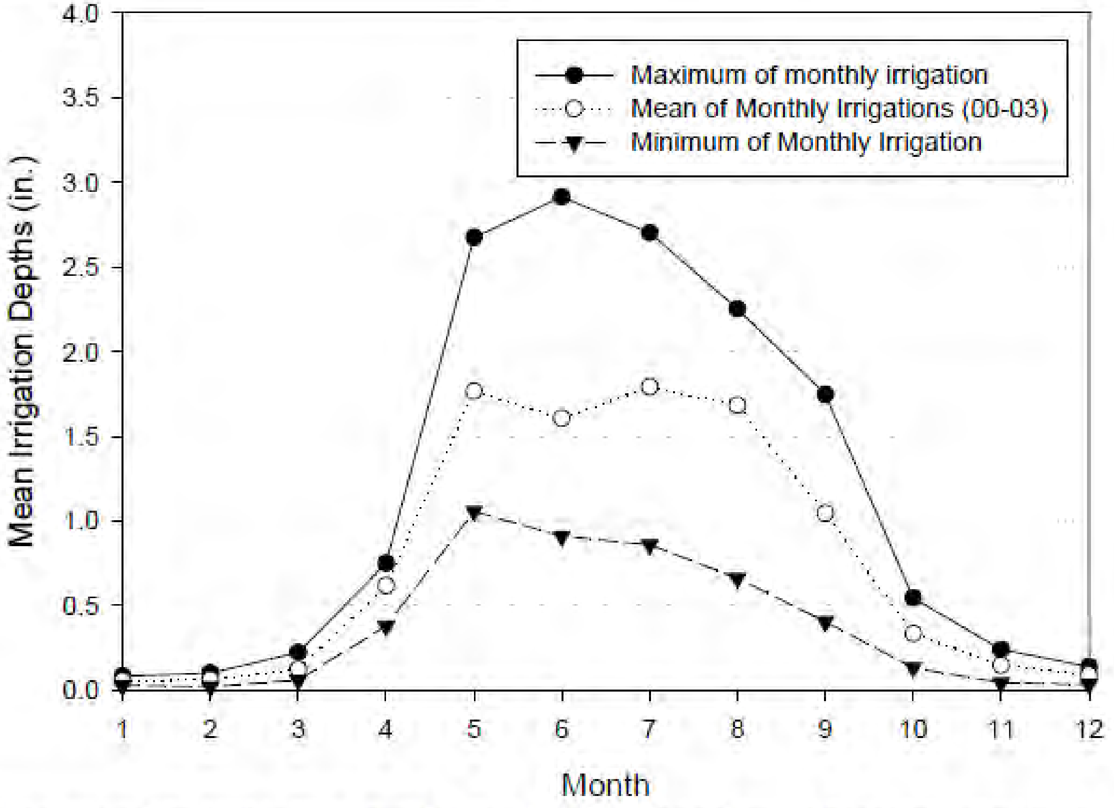
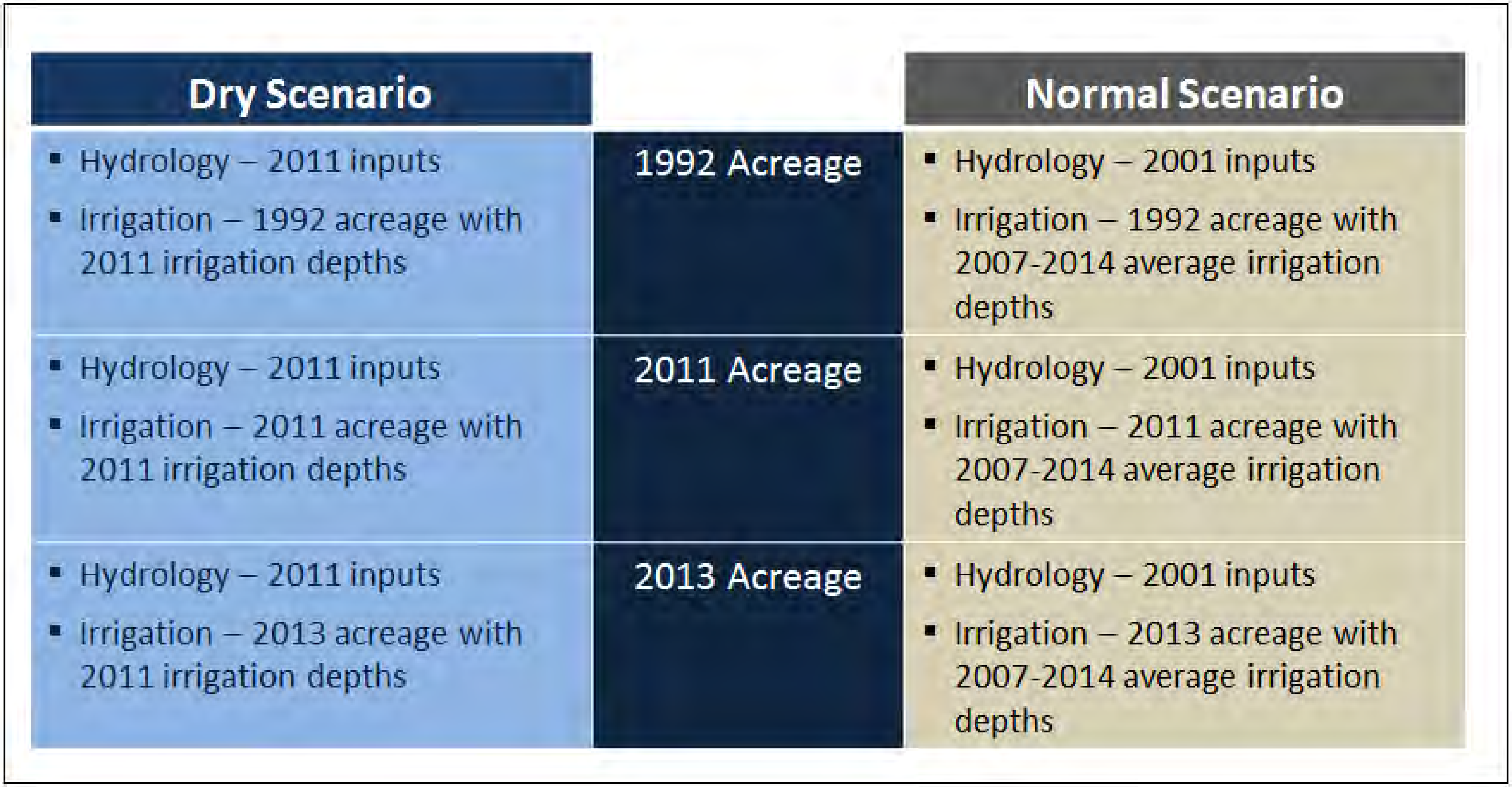


Figure 3-6. Mean monthly irrigation depths for fields in Southwest Georgia supplied by groundwater and maximum and minimum monthly amounts observed during 2000 to 2003.

Panday Demo. 10 — Hook (2005) (JX-017), Fig. 3-6 showing mean monthly irrigation depths for fields in Southwest Georgia supplied by groundwater and maximum and minimum monthly amounts observed during 2000 to 2003.

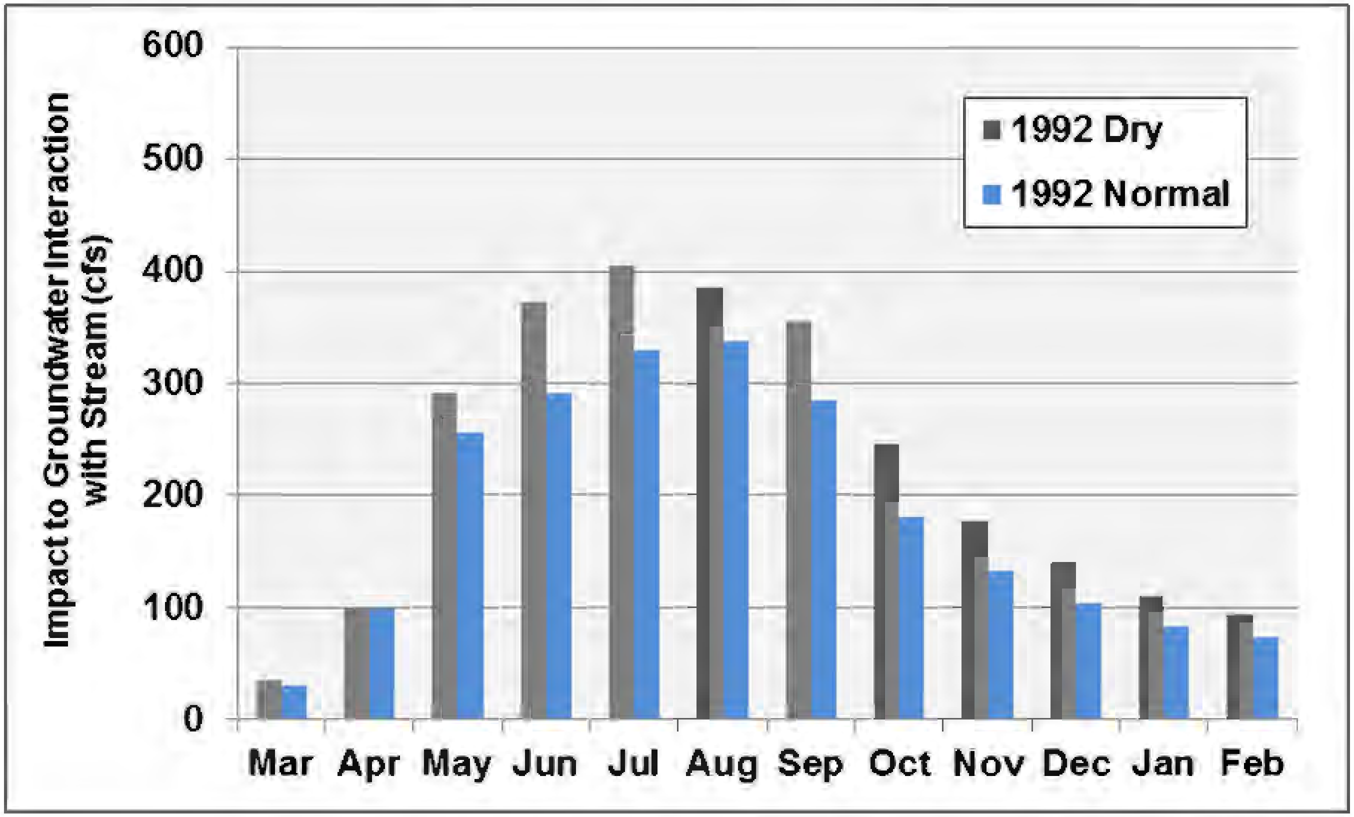


Dry Scenario		Normal Scenario
Hydrology – 2011 inputs Irrigation – 1992 acreage with 2011 irrigation depths	1992 Acreage	Hydrology – 2001 inputs Irrigation – 1992 acreage with 2007-2014 average irrigation depths
Hydrology – 2011 inputs Irrigation – 2011 acreage with 2011 irrigation depths	2011 Acreage	Hydrology – 2001 inputs Irrigation – 2011 acreage with 2007-2014 average irrigation depths
Hydrology – 2011 inputs Irrigation – 2013 acreage with 2011 irrigation depths	2013 Acreage	Hydrology – 2001 inputs Irrigation – 2013 acreage with 2007-2014 average irrigation depths

Panday Demo. 11 — Description of Model Inputs for Dry and Normal Scenarios.

Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

1992 Irrigated Acreages:

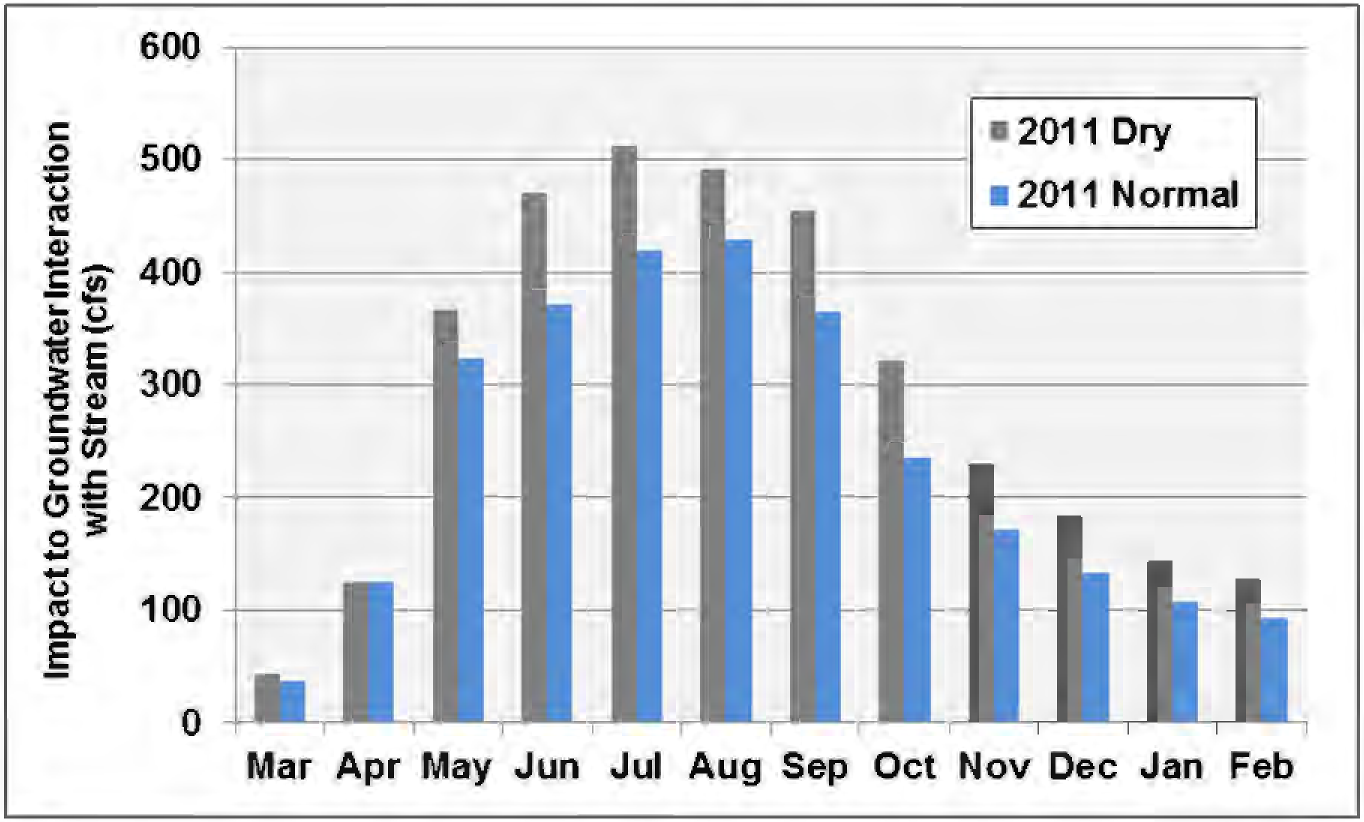


Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

Panday Demo. 12 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.

Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

2011 Irrigated Acreages:

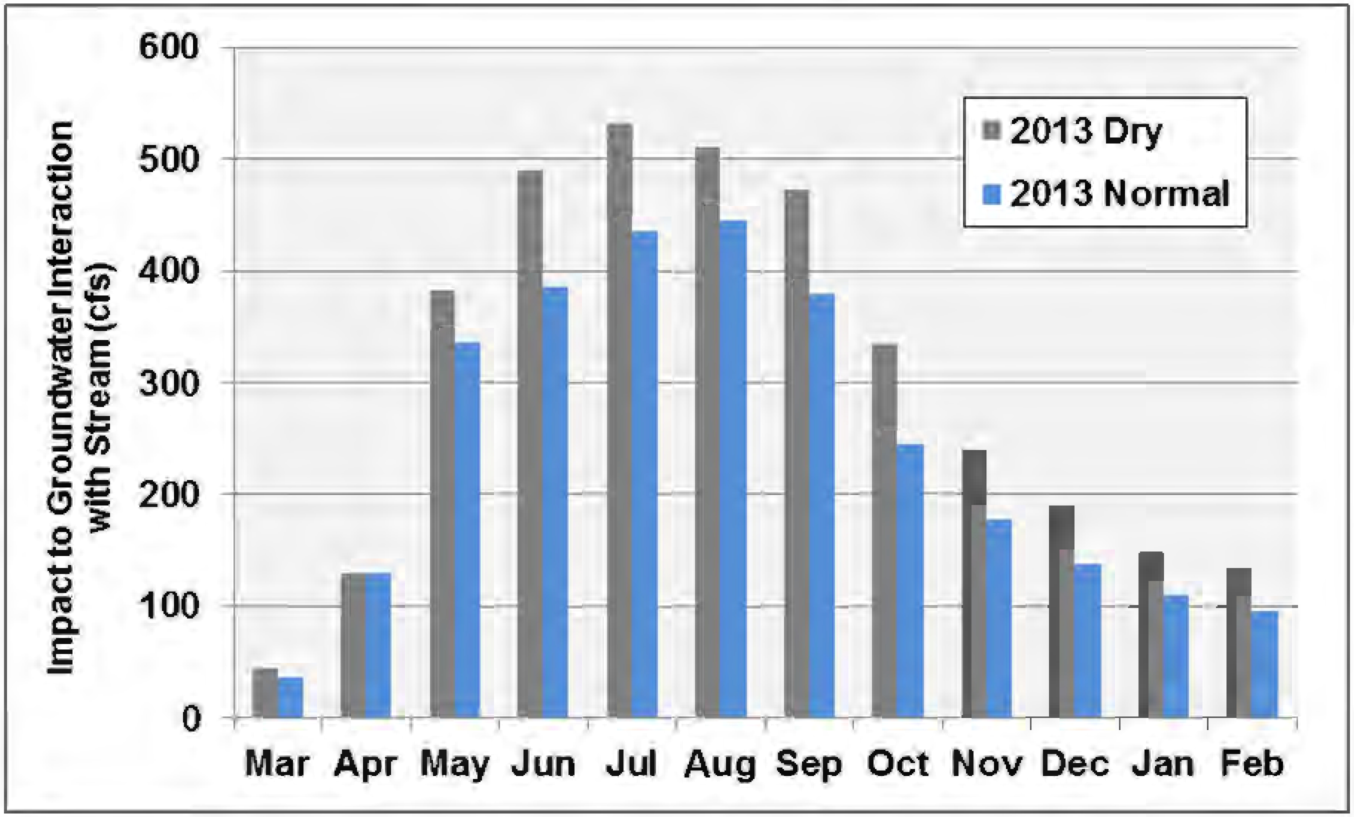


Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

Panday Demo. 13 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.

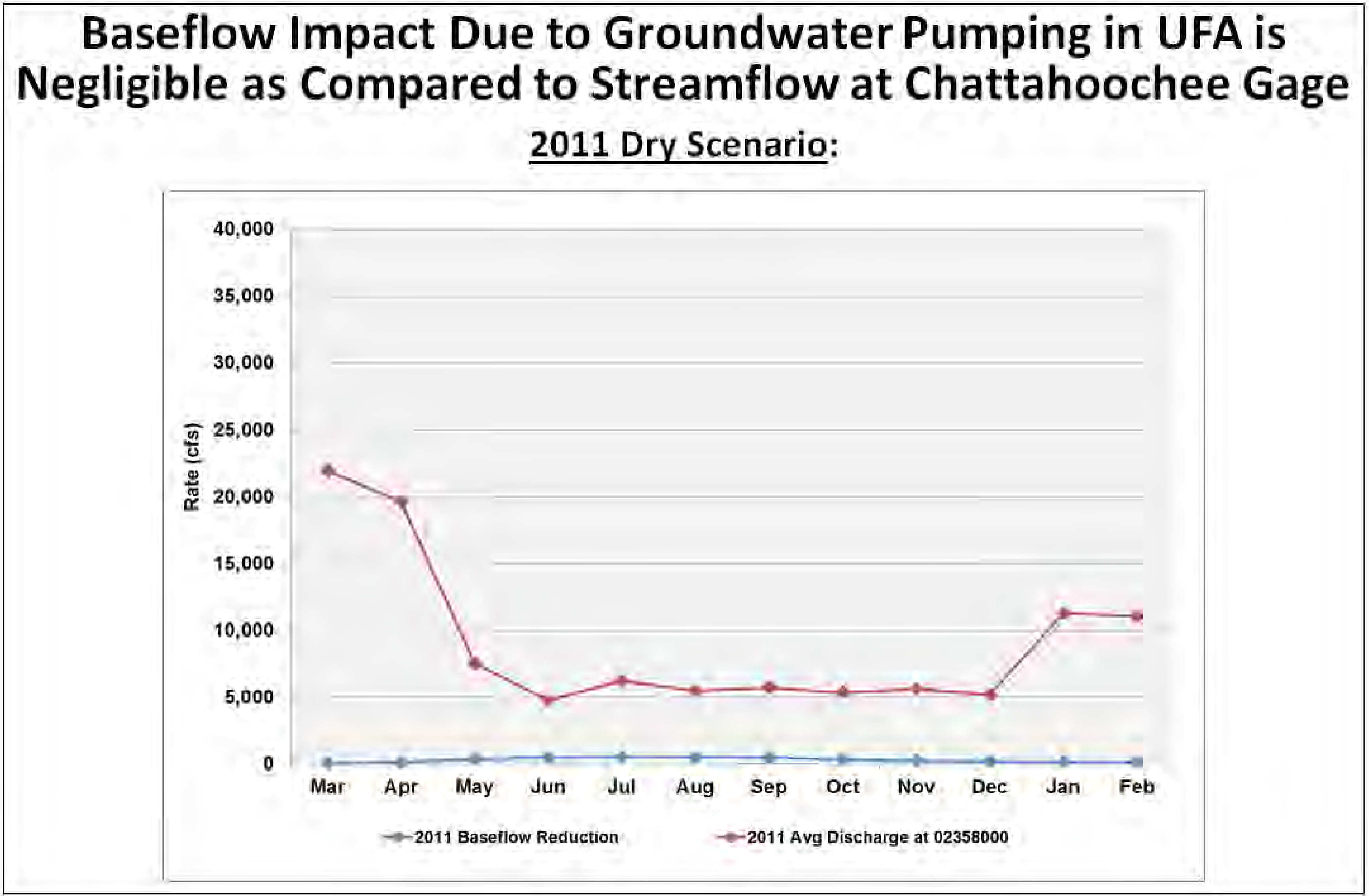
Modeled Impact to Streamflow in the Lower ACF River Basin from Pumping the UFA within Georgia

2013 Irrigated Acreages:



Note: Georgia's impact is 95% of impact of pumping from all states within the Lower ACF River Basin (i.e., Georgia, Florida, and Alabama).

Panday Demo. 14 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-3.



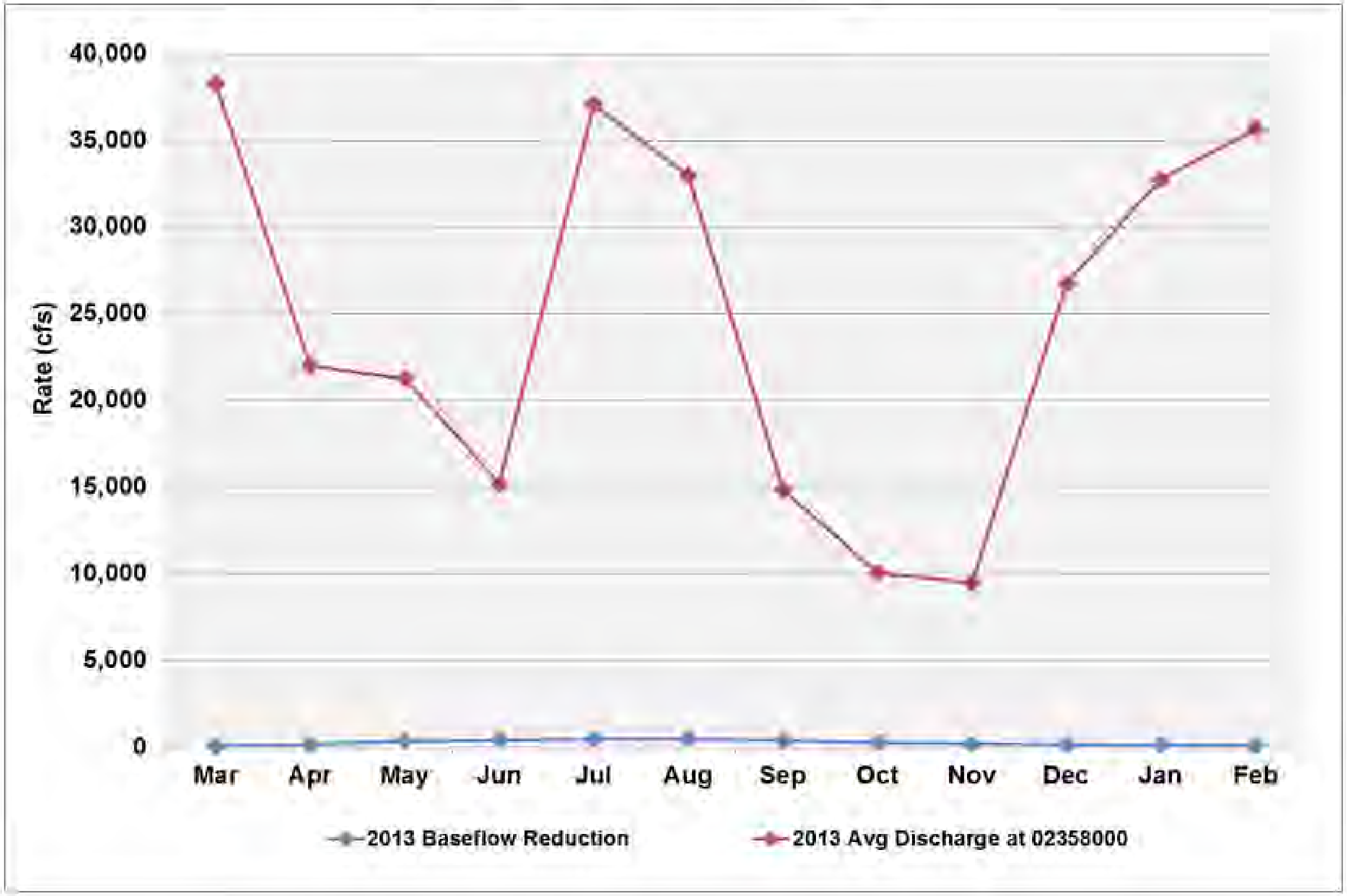
Baseflow Impact Due to Groundwater Pumping in UFA is Negligible as Compared to Streamflow at Chattahoochee Gage

2011 Dry Scenario:

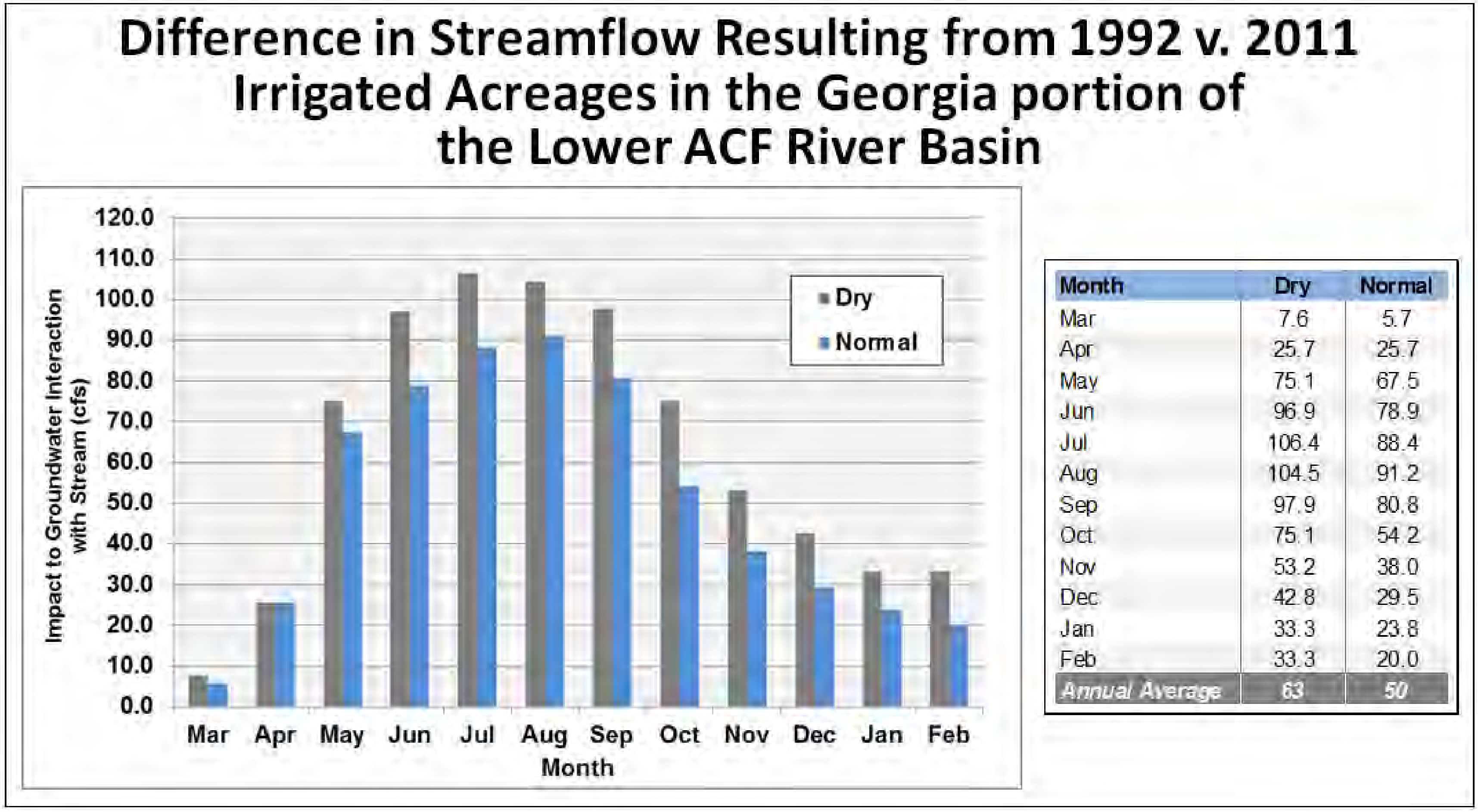
**Panday Demo. 15 — Created from data in Panday Expert Report (GX-0873), 20 May 2016, Revised Fig. E-9.
Flow data from Chattahoochee gage was obtained from the USGS (JX-128).**

Baseflow Impact Due to Groundwater Pumping in UFA is Negligible as Compared to Streamflow at Chattahoochee Gage

2013 Normal Scenario:



Panday Demo. 16 — Created using data from Panday Expert Report (GX-0873), 20 May 2016, Revised Figure E-9. Flow data from Chattahoochee gage was obtained from the USGS (JX-128).

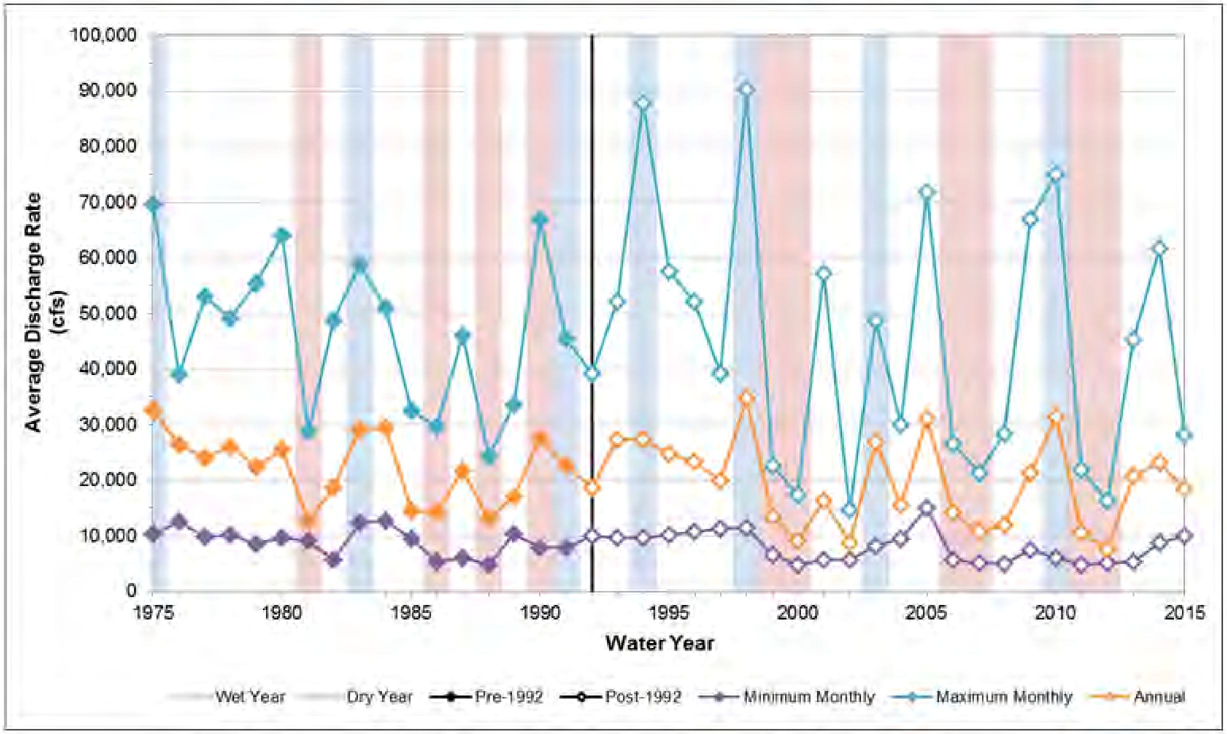


Difference in Streamflow Resulting from 1992 v. 2011 Irrigated Acreages in the Georgia portion of the Lower ACF River Basin

Month	Dry	Normal
Mar	7.6	5.7
Apr	25.7	25.7
May	75.1	67.5
Jun	96.9	78.9
Jul	106.4	88.4
Aug	104.5	91.2
Sep	97.9	80.8
Oct	75.1	54.2
Nov	53.2	38.0
Dec	42.8	29.5
Jan	33.3	23.8
Feb	33.3	20.0
Annual Average	*63*	*50*

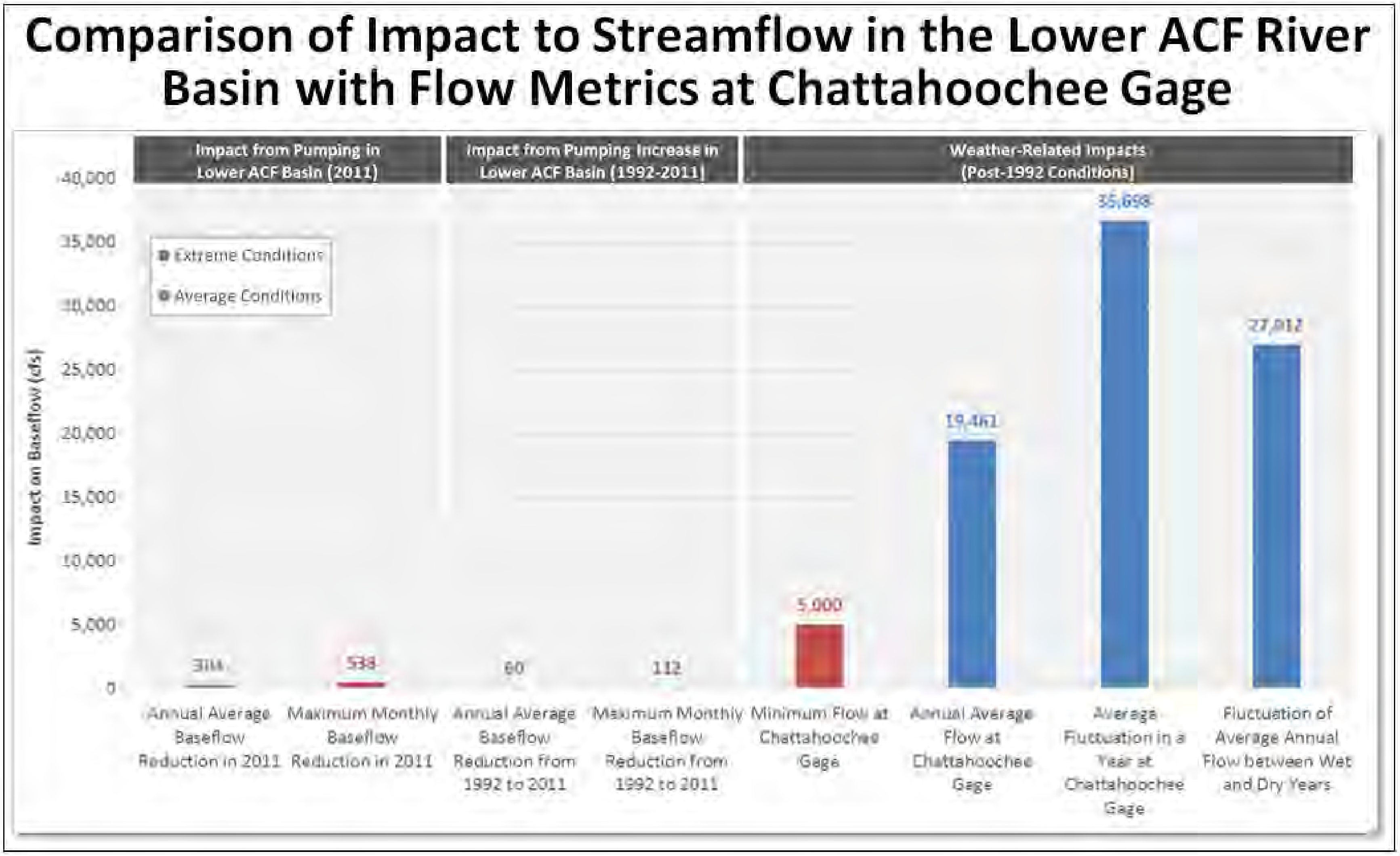
Panday Demo. 17 — Panday Expert Report (GX-0873), 20 May 2016, Fig. E-4.

Streamflow at the Chattahoochee Gage



Time Period	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Average Discharge Rate (cfs)												
Minimum Monthly	4,750	4,781	7,885	5,573	9,476	7,810	10,423	9,980	12,635	15,087	8,968	7,986
Maximum Monthly	24,162	14,771	33,539	25,569	48,736	42,258	55,477	58,641	69,543	90,332	46,812	44,684
Annual	12,661	7,605	17,041	13,085	22,697	19,295	26,452	25,340	32,718	34,617	22,231	19,461

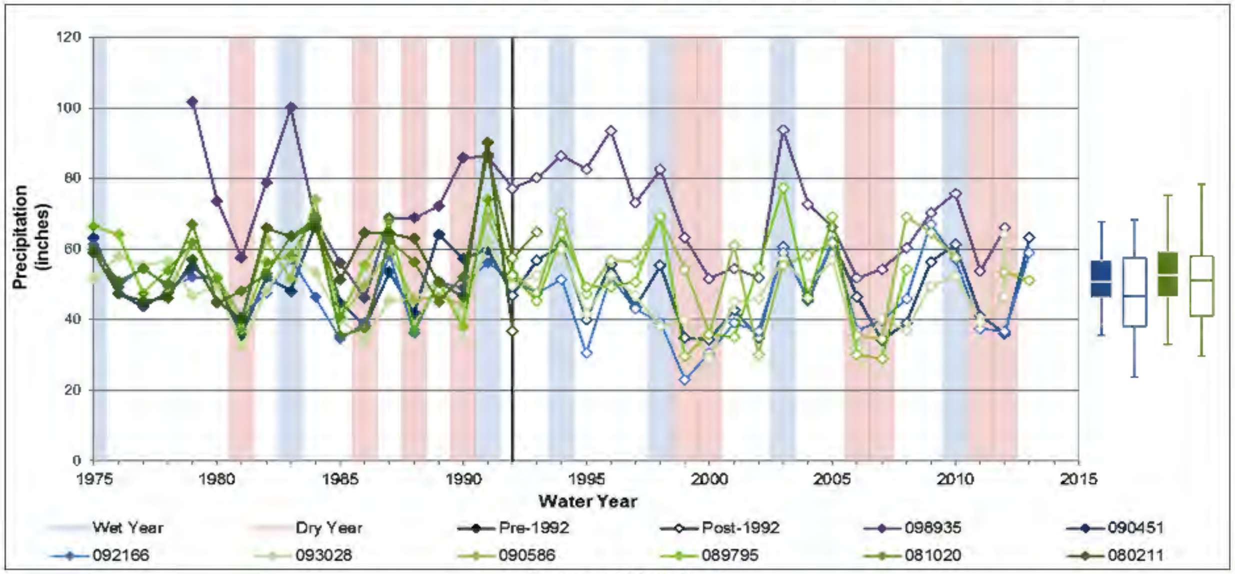
**Panday Demo. 18 — Source: Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-4.
Flow data from Chattahoochee gage was obtained from the USGS (JX-128).**



Comparison of Impact to Streamflow in the Lower ACF River Basin with Flow Metrics at Chattahoochee Gage

**Panday Demo. 19 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 3-4.
Flow data was obtained from the USGS (JX-128).**

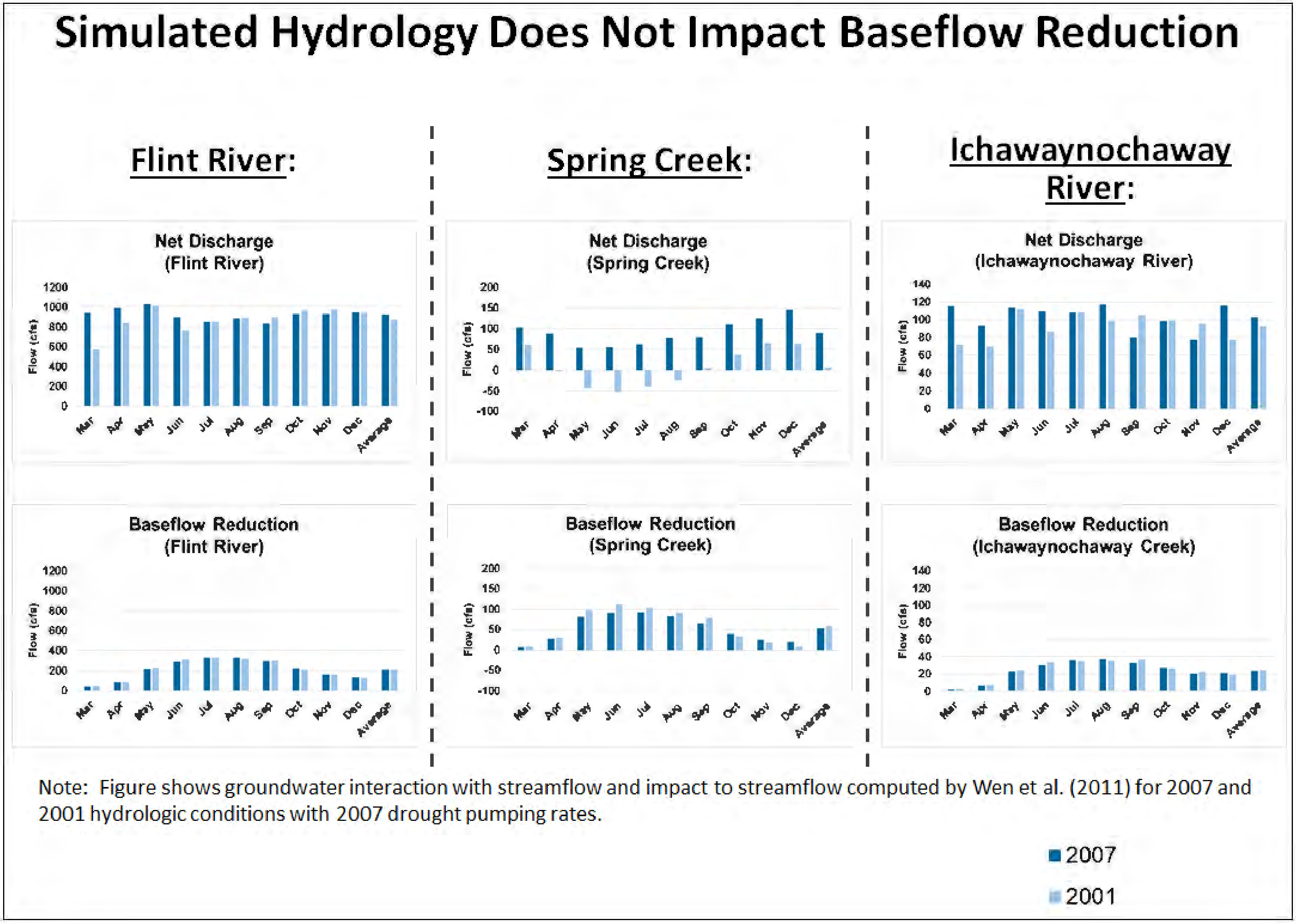
Precipitation at Select NOAA Stations within the ACF River Basin



Summary Statistics

NOAA Station ID	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Precipitation (inches)												
098935	46.1	51.7	68.6	54.5	72.1	70.3	85.9	80.2	101.7	93.8	74.2	69.6
Upper ACF River Basin	***34.6***	***23.0***	***45.2***	***37.4***	***49.6***	***45.7***	***55.9***	***56.5***	***66.6***	***67.1***	***50.1***	***46.5***
090451	35.8	34.2	44.8	39.3	49.8	46.0	57.3	56.8	66.6	63.2	51.1	47.8
092166	34.6	23.0	46.3	37.1	49.4	44.5	54.7	52.1	61.3	67.1	49.1	45.1
Lower ACF River Basin	***32.1***	***29.0***	***45.6***	***40.1***	***51.6***	***50.3***	***58.5***	***57.0***	***74.2***	***77.4***	***52.2***	***49.9***
093028	32.1	29.1	45.6	40.0	49.9	46.6	55.4	52.5	62.2	64.1	48.8	46.6
090586	40.4	30.2	45.8	47.5	50.6	56.5	61.3	61.5	74.2	70.0	53.3	53.6
089795	37.3	29.0	47.4	40.5	55.5	50.7	64.1	54.4	74.0	77.4	54.8	49.8
081020	35.5	–	48.1	–	53.0	–	62.3	–	86.9	–	55.1	–
080211	40.2	–	46.6	–	57.0	–	64.6	–	90.2	–	56.9	–
Upper and Lower ACF Basin	***32.1***	***23.0***	***45.5***	***39.1***	***50.9***	***48.5***	***57.7***	***56.9***	***74.2***	***77.4***	***51.4***	***48.4***

Panday Demo. 20 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure C-2.
Data obtained from GA-1156, NOAA.



Simulated Hydrology Does Not Impact Baseflow Reduction

Flint River:

Spring Creek:

Ichawaynochaway River:

Net Discharge (Flint River)

Net Discharge (Spring Creek)

Net Discharge (Ichawaynochaway River)

Baseflow Reduction (Flint River)

Baseflow Reduction (Spring Creek)

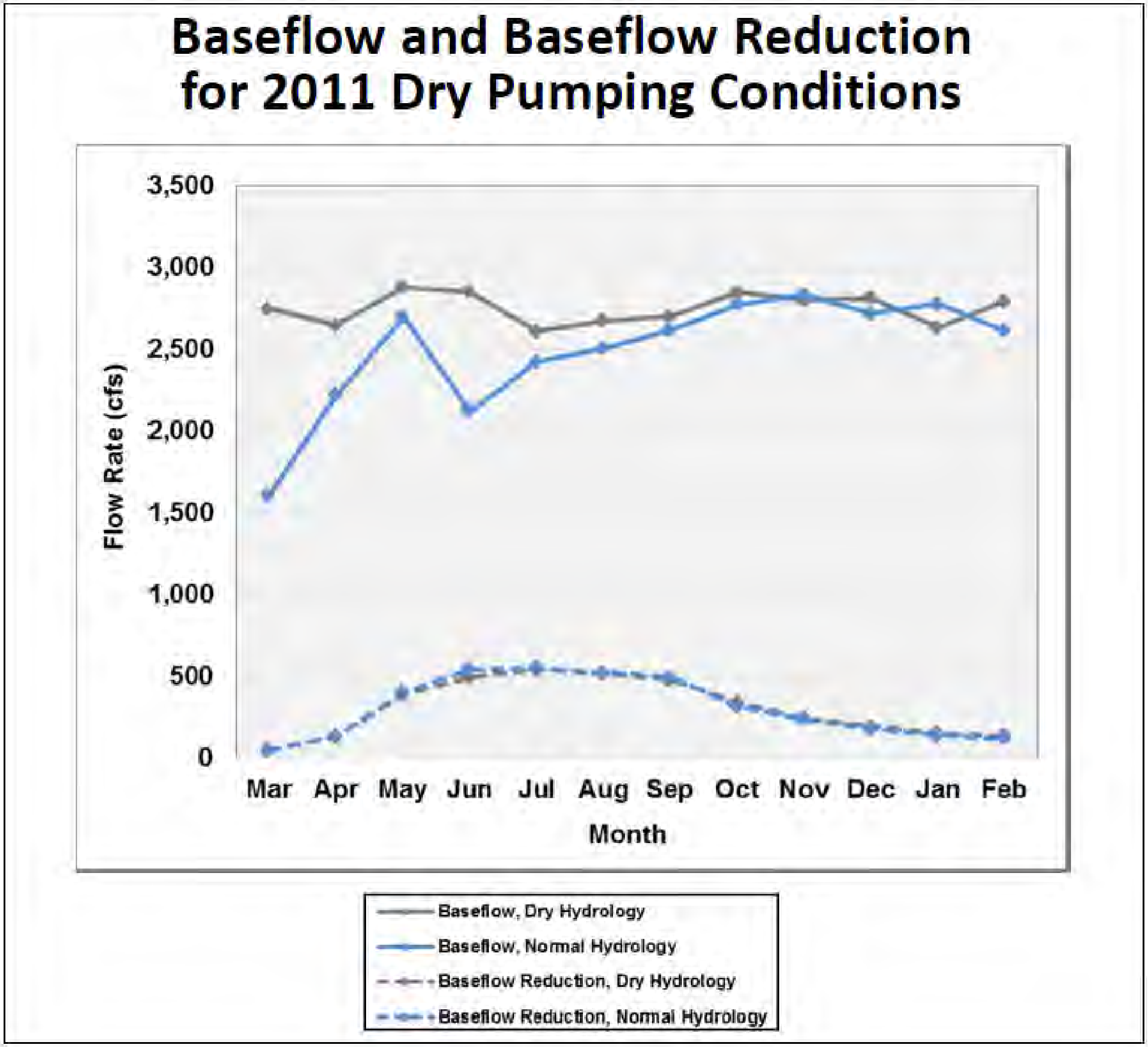
Baseflow Reduction (Ichawaynochaway Creek)

Note: Figure shows groundwater interaction with streamflow and impact to streamflow computed by Wen et al. (2011) for 2007 and 2001 hydrologic conditions with 2007 drought pumping rates.

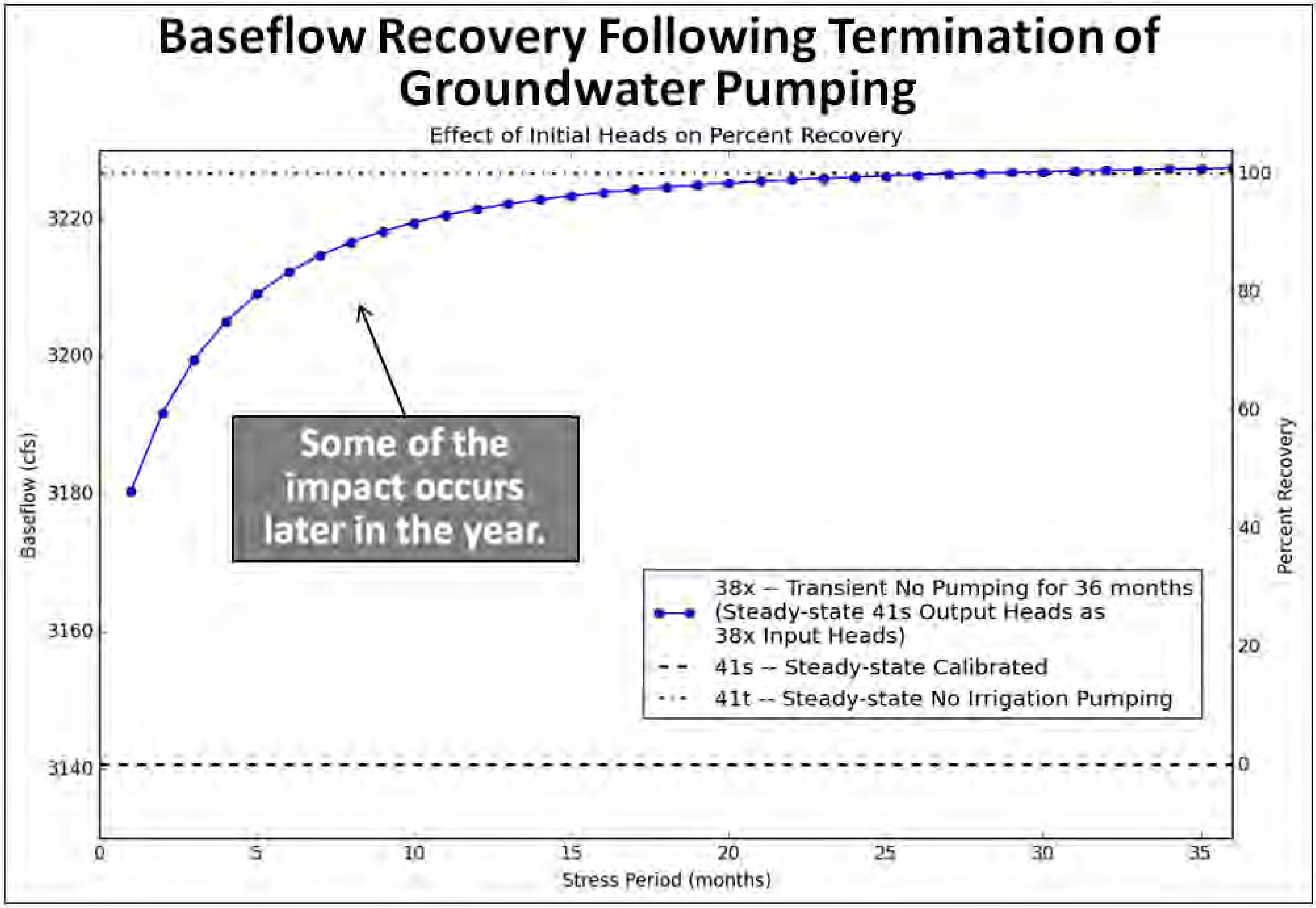
■ 2007

■ 2001

Panday Demo. 21 —Panday Expert Report (GX-0873), 20 May 2016, Fig. 4-6.



Panday Demo. 22 — Baseflow and Baseflow Reduction for 2011 Dry Pumping Conditions

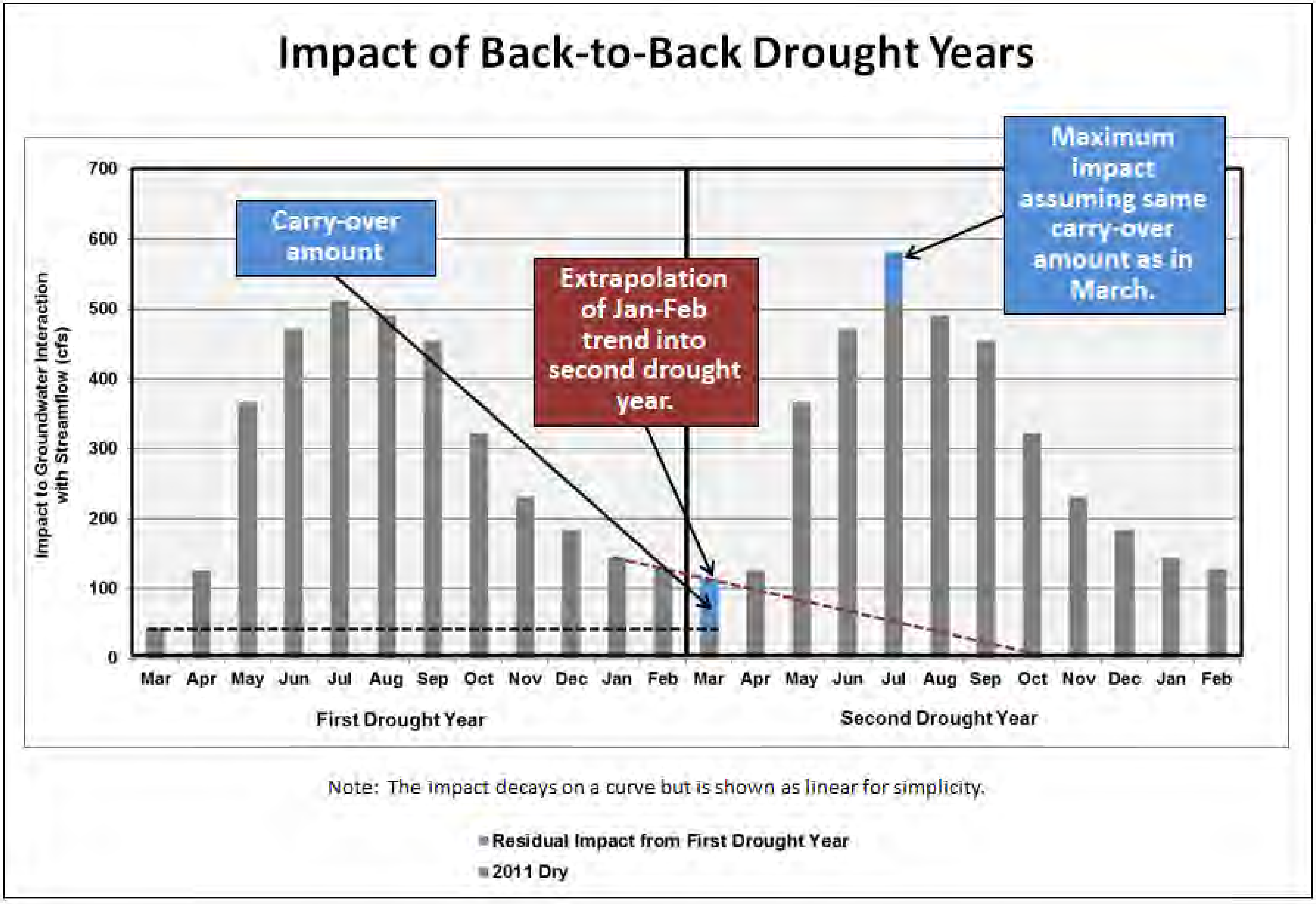


Baseflow Recovery Following Termination of Groundwater Pumping

Effect of Initial Heads on Percent Recovery

Some of the impact occurs later in the year.

Panday Demo. 23 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 5-7.



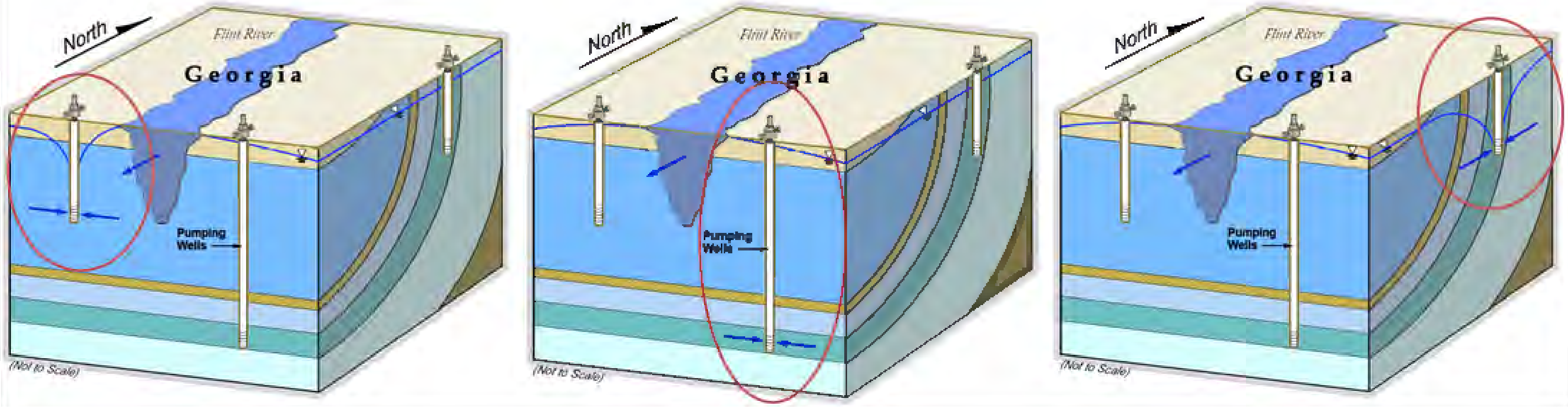
Panday Demo. 24 — Created using data from Panday Expert Report (GX-0873), 20 May 2016, Fig. E-3.

Effects of Groundwater Pumping on Rivers in the ACF River Basin

Pumping from Upper Floridan Aquifer :

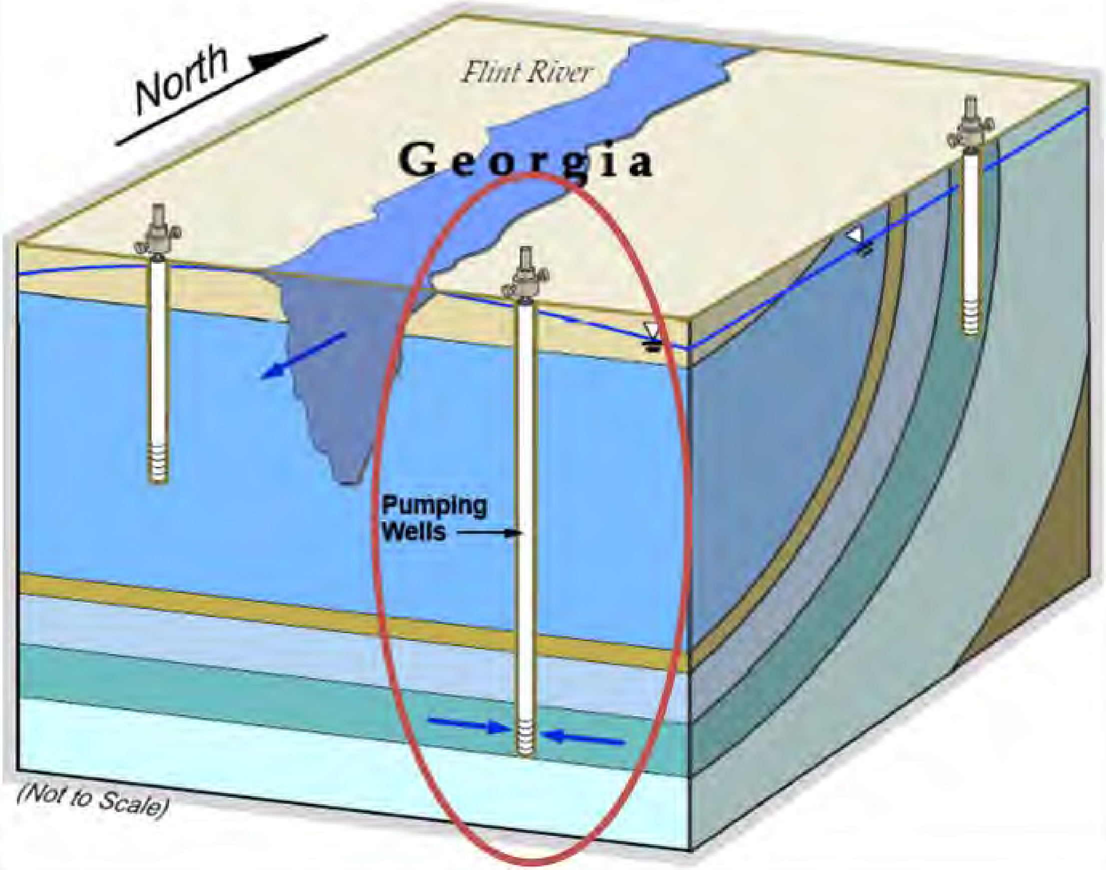
Pumping from Deeper Clayton Aquifer:

Pumping from Outcropped Clayton Aquifer:



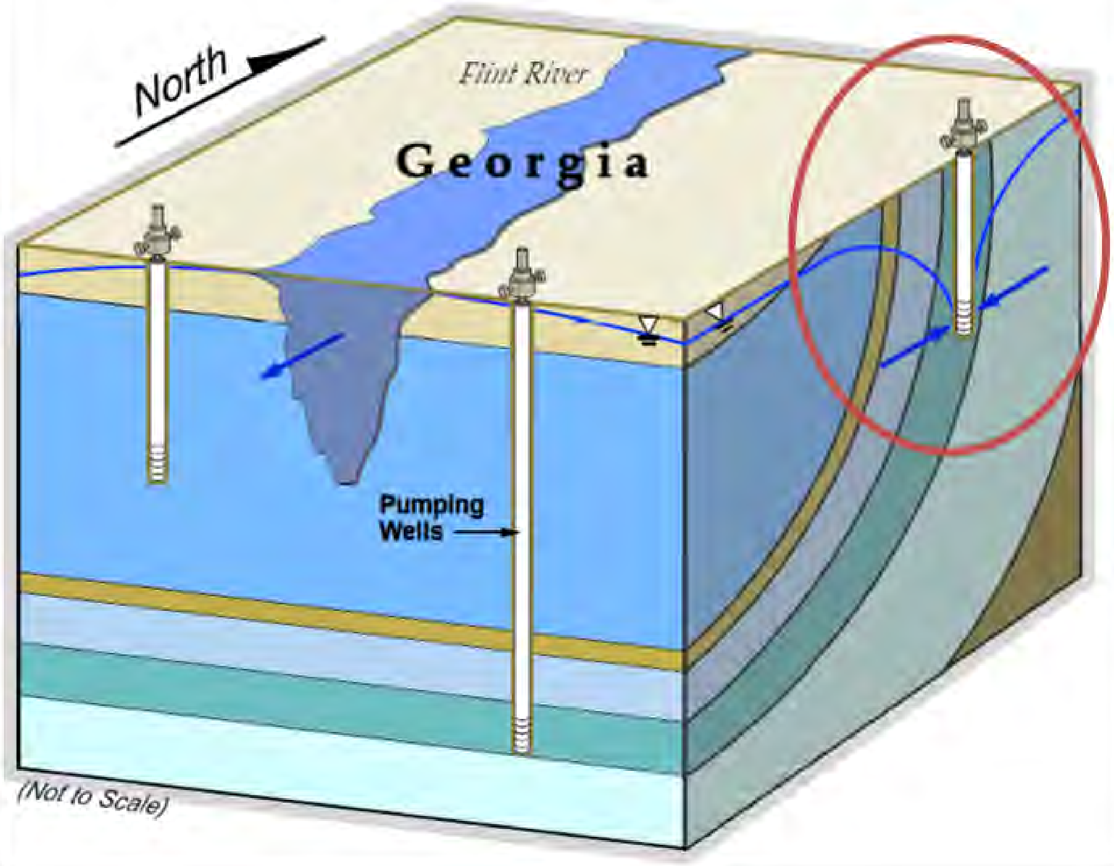
Panday Demo. 25 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

Pumping from Deeper Clayton Aquifer:

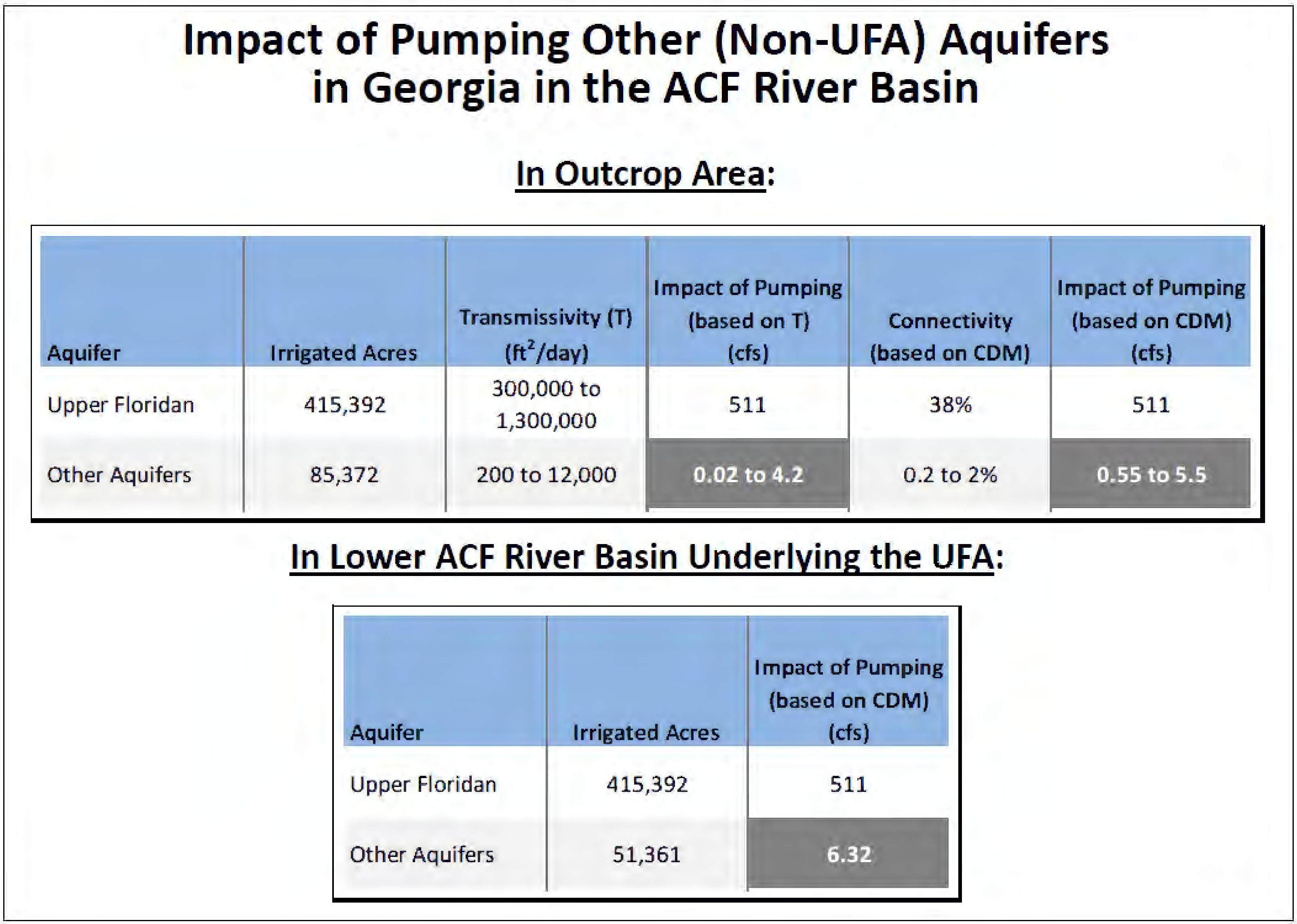


Panday Demo. 26 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.

Pumping from Outcropped Clayton Aquifer:



Panday Demo. 27 — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig. D-2.



Impact of Pumping Other (Non-UFA) Aquifers in Georgia in the ACF River Basin

In Outcrop Area:

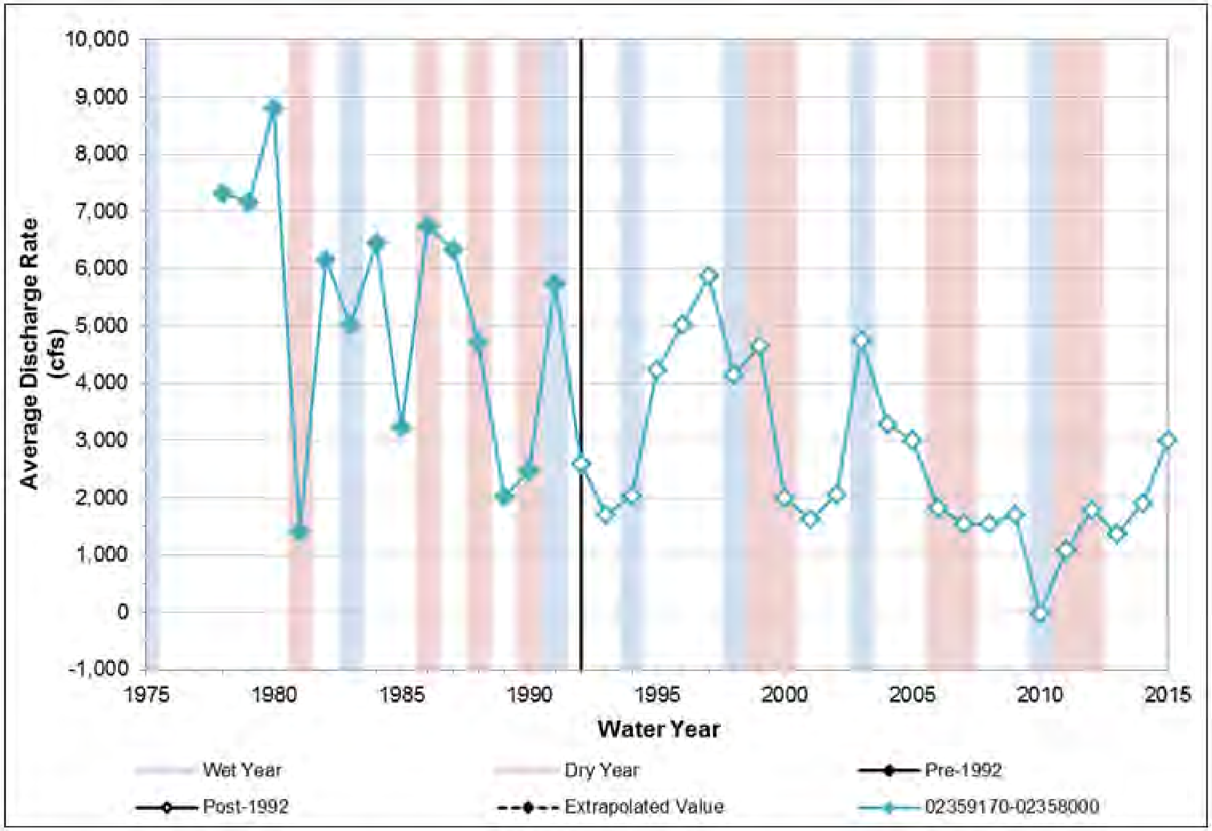
Aquifer	Irrigated Acres	Transmissivity (T) (ft^2/day)	Impact of Pumping (based on T) (cfs)	Connectivity (based on CDM)	Impact of Pumping (based on CDM) (cfs)
Upper Floridan	415,392	300,000 to 1,300,000	511	38%	511
Other Aquifers	85,372	200 to 12,000	**0.02 to 4.2**	0.2 to 2%	**0.55 to 5.5**

In Lower ACF River Basin Underlying the UFA:

Aquifer	Irrigated Acres	Impact of Pumping (based on CDM) (cfs)
Upper Floridan	415,392	511
Other Aquifers	51,361	**6.32**

Panday Demo. 28 — Source: Panday Memorandum 22 July 2016.

Streamflow Budget of the Apalachicola River

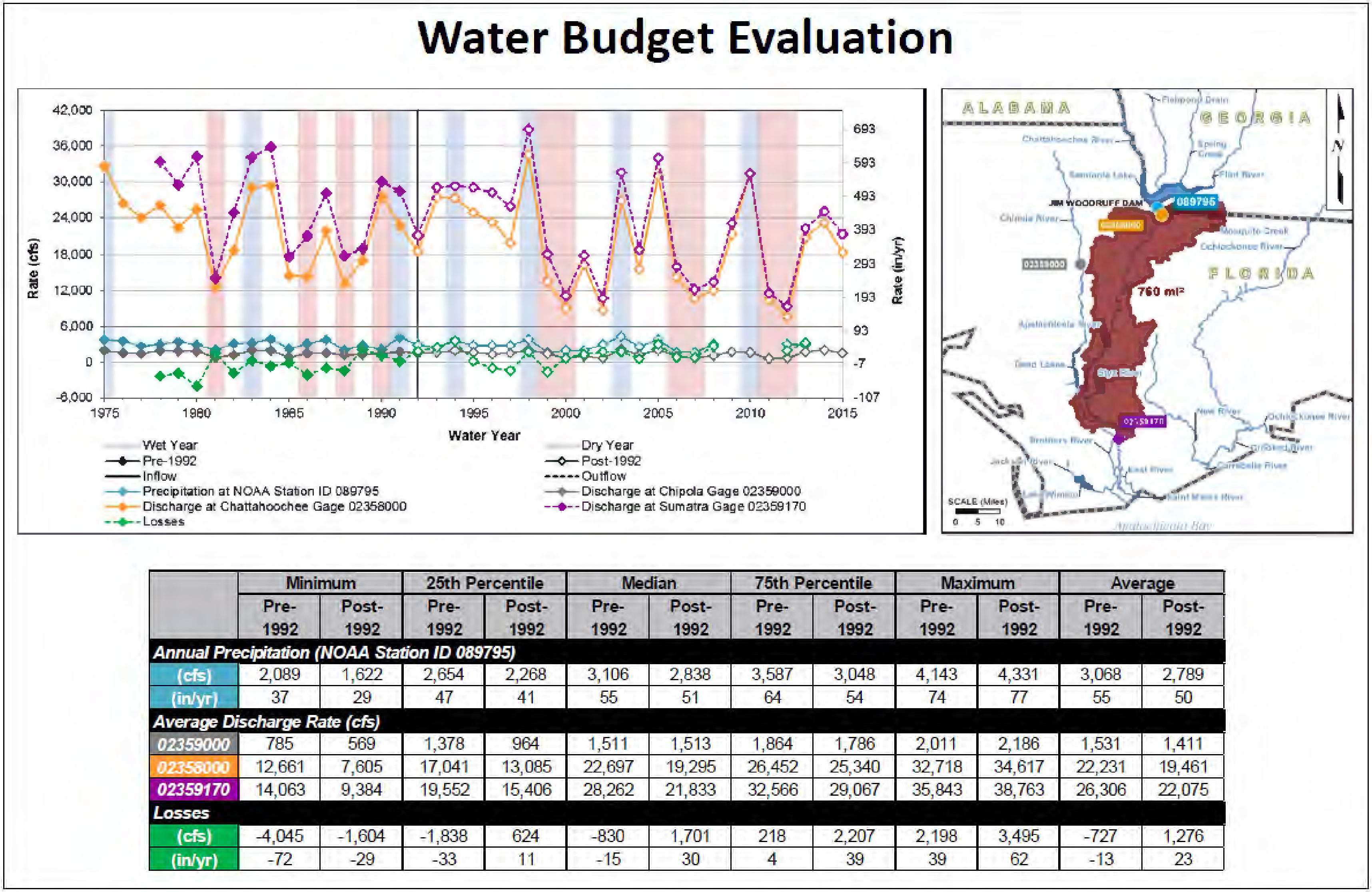


USGS Station ID	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Average Discharge Rate (cfs)												
02359170-02358000	1,402	-15	3,591	1,683	5,950	2,019	6,670	3,499	8,801	5,868	5,254	2,614

Panday Demo. 29 — Panday Expert Report (GX-0873), 20 May 2016, Fig. 3-6.

Apalachicola River Water Budget	
Inflows	**Outflows**
• Chattahoochee Gage (USGS Station ID 02358000)	• Sumatra Gage (USGS Station ID 02359170)
• Chipola Gage (USGS Station ID 02359000)	• Other outflows or losses
• Precipitation (NOAA 089795 over basin area)	

Panday Demo. 30 – Inflow and Outflow Components of the Basin-Wide Water Budget Between Chattahoochee and Sumatra Gages.



Water Budget Evaluation

	Minimum		25th Percentile		Median		75th Percentile		Maximum		Average	
	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992	Pre-1992	Post-1992
Annual Precipitation (NOAA Station ID 089795)												
(cfs)	2,089	1,622	2,654	2,268	3,106	2,838	3,587	3,048	4,143	4,331	3,068	2,789
(in/yr)	37	29	47	41	55	51	64	54	74	77	55	50
Average Discharge Rate (cfs)												
02359000	785	569	1,378	964	1,511	1,513	1,864	1,786	2,011	2,186	1,531	1,411
02358000	12,661	7,605	17,041	13,085	22,697	19,295	26,452	25,340	32,718	34,617	22,231	19,461
02359170	14,063	9,384	19,552	15,406	28,262	21,833	32,566	29,067	35,843	38,763	26,306	22,075
Losses												
(cfs)	-4,045	-1,604	-1,838	624	-830	1,701	218	2,207	2,198	3,495	-727	1,276
(in/yr)	-72	-29	-33	11	-15	30	4	39	39	62	-13	23

Panday Demo. 31 –Water Budget Evaluation.

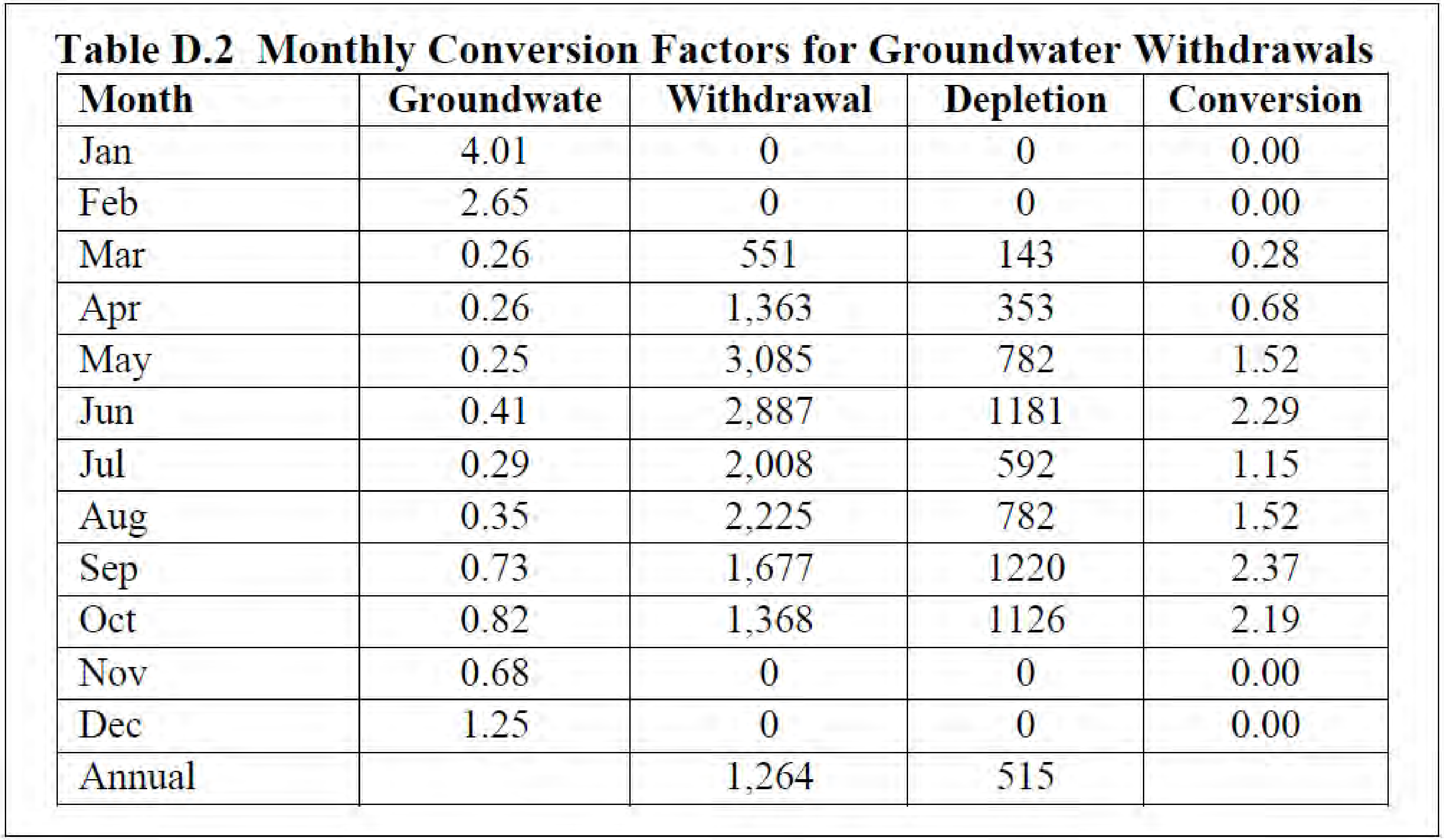
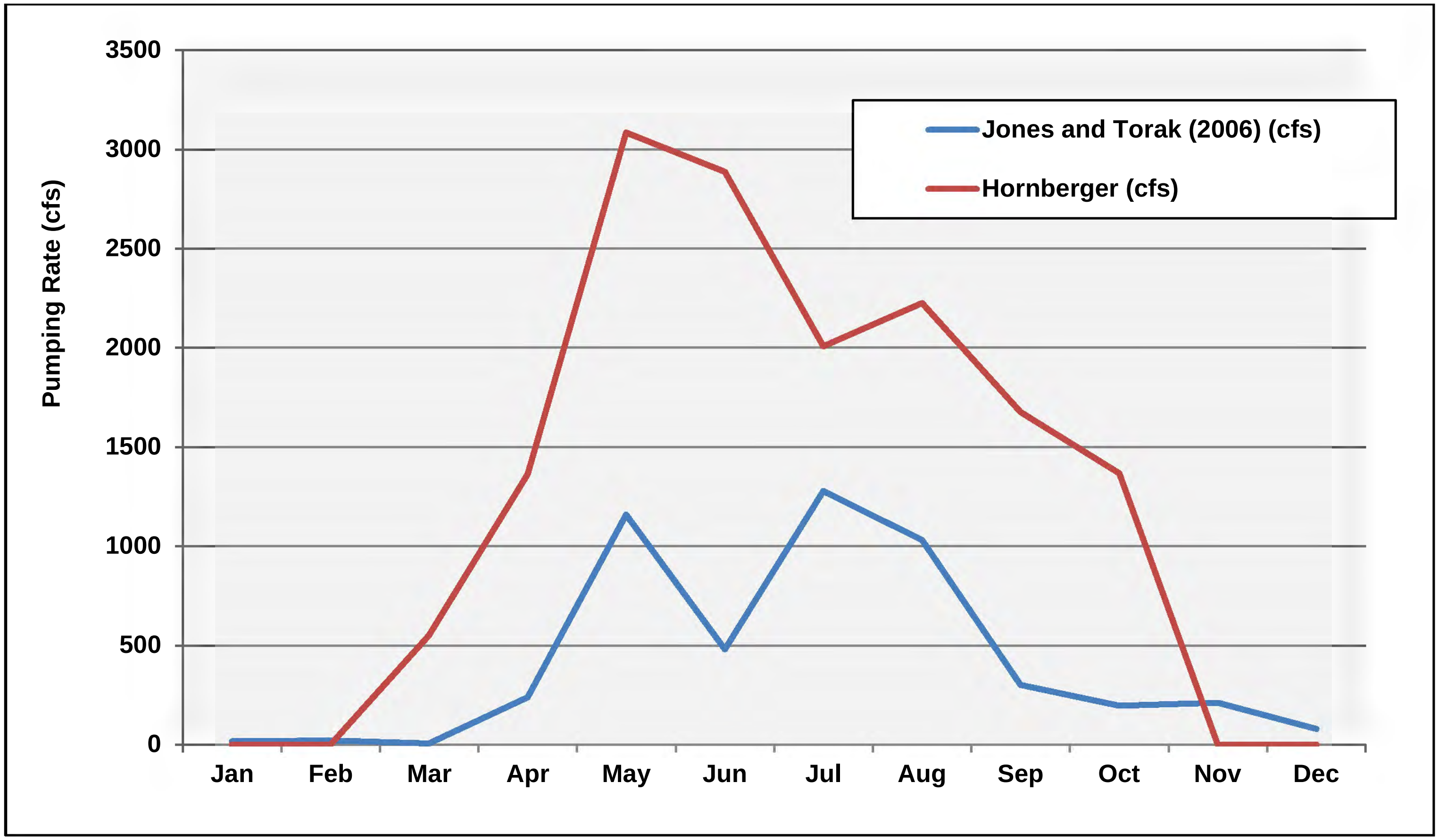


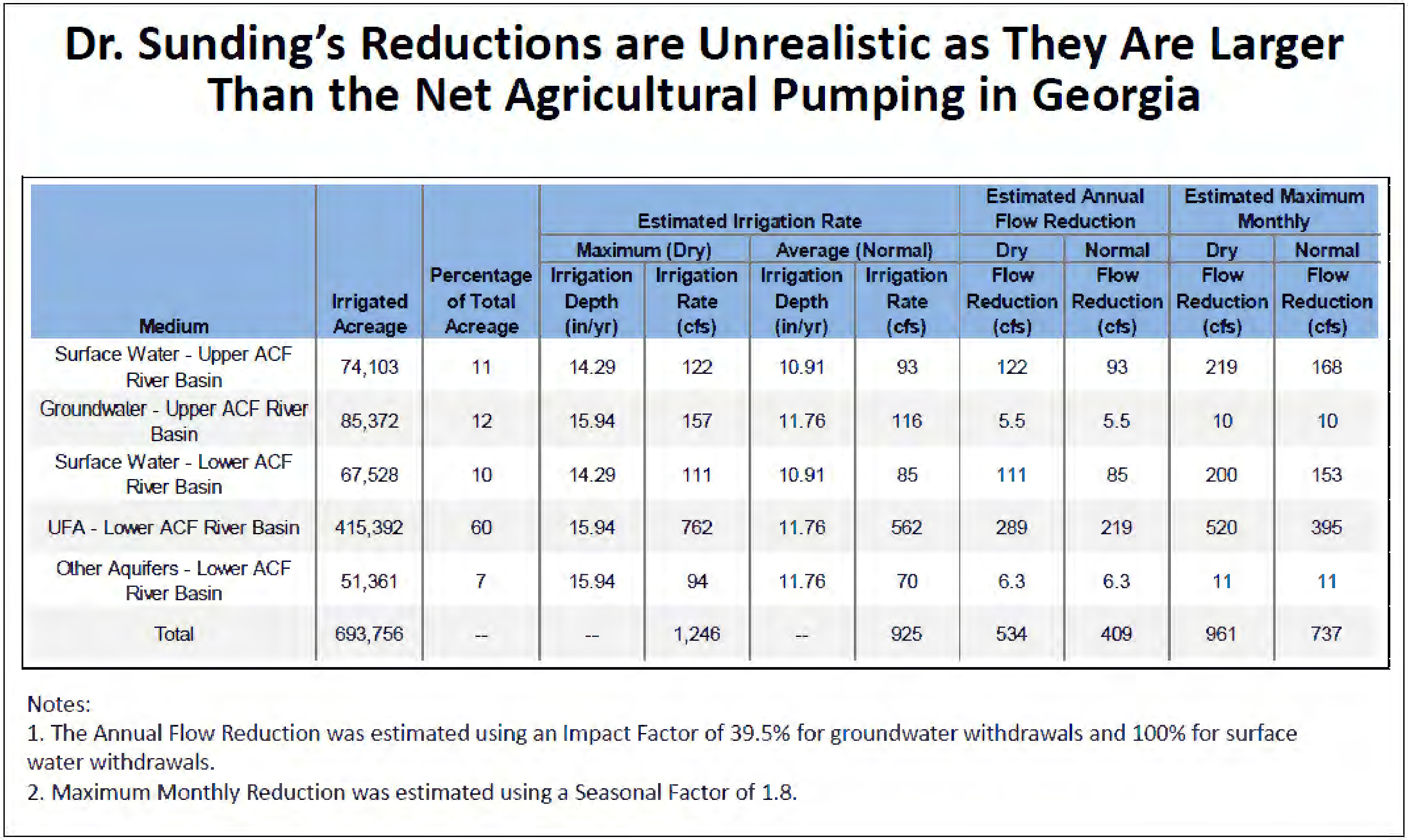
Table D.2 Monthly Conversion Factors for Groundwater Withdrawals

Month	Groundwate	Withdrawal	Depletion	Conversion
Jan	4.01	0	0	0.00
Feb	2.65	0	0	0.00
Mar	0.26	551	143	0.28
Apr	0.26	1,363	353	0.68
May	0.25	3,085	782	1.52
Jun	0.41	2,887	1181	2.29
Jul	0.29	2,008	592	1.15
Aug	0.35	2,225	782	1.52
Sep	0.73	1,677	1220	2.37
Oct	0.82	1,368	1126	2.19
Nov	0.68	0	0	0.00
Dec	1.25	0	0	0.00
Annual		1,264	515	

Panday Demo. 32 — Table D.2 from Hornberger Expert Report (FX-0785), 29 February 2016.



Panday Demo. 33 — Comparison of Pumping Distributions from Jones and Torak (2006) (JX-018) and Hornberger (29 February 2016, Table D.2) (FX-0785).



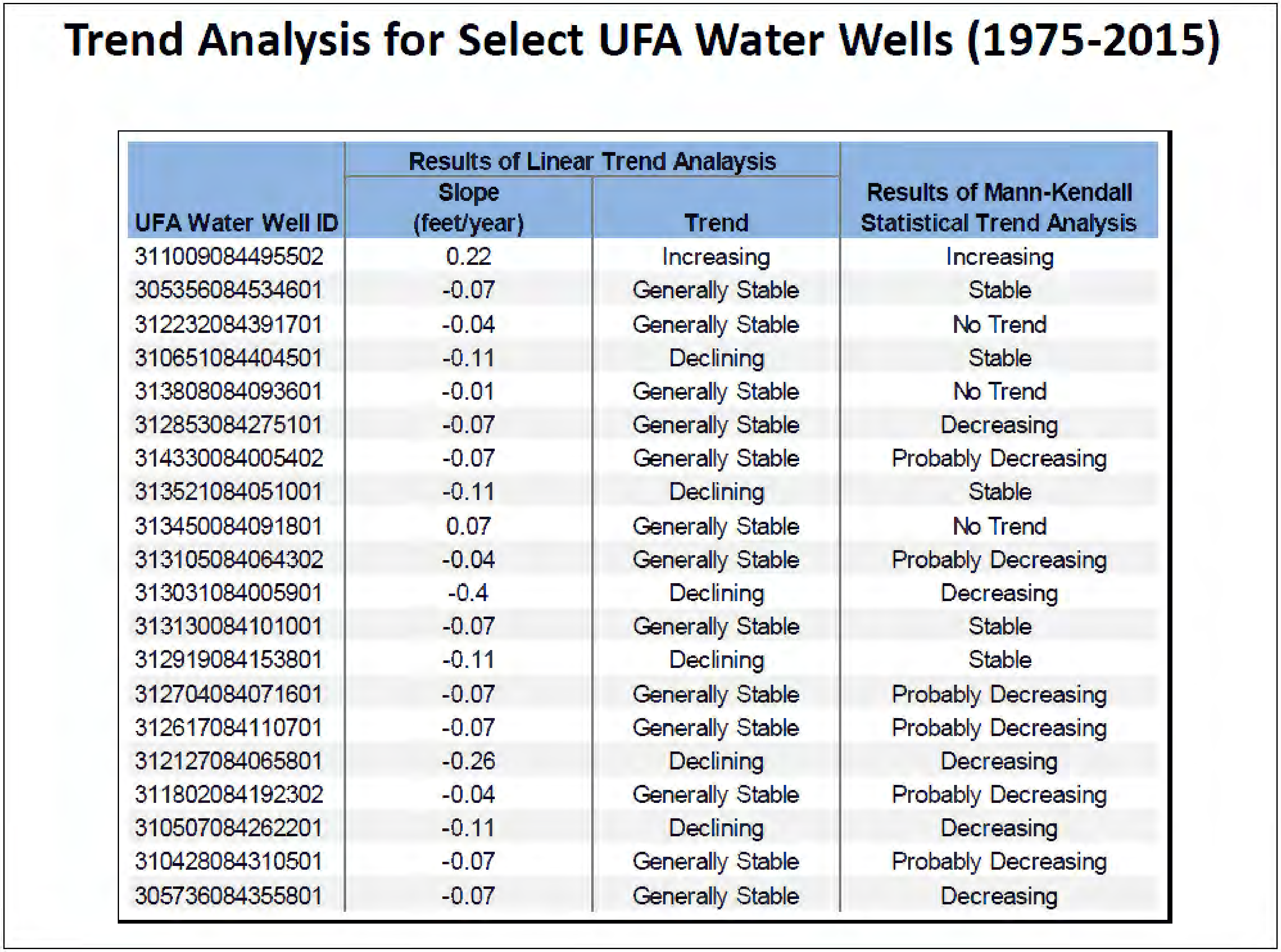
Dr. Sunding's Reductions are Unrealistic as They Are Larger Than the Net Agricultural Pumping in Georgia

			Estimated Irrigation Rate				Estimated Annual Flow Reduction		Estimated Maximum Monthly	
			Maximum (Dry)		Average (Normal)		Dry	Normal	Dry	Normal
Medium	Irrigated Acreage	Percentage of Total Acreage	Irrigation Depth (in/yr)	Irrigation Rate (cfs)	Irrigation Depth (in/yr)	Irrigation Rate (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)	Flow Reduction (cfs)
Surface Water - Upper ACF River Basin	74,103	11	14.29	122	10.91	93	122	93	219	168
Groundwater - Upper ACF River Basin	85,372	12	15.94	157	11.76	116	5.5	5.5	10	10
Surface Water - Lower ACF River Basin	67,528	10	14.29	111	10.91	85	111	85	200	153
UFA - Lower ACF River Basin	415,392	60	15.94	762	11.76	562	289	219	520	395
Other Aquifers - Lower ACF River Basin	51,361	7	15.94	94	11.76	70	6.3	6.3	11	11
Total	693,756	--	--	1,246	--	925	534	409	961	737

Notes:

1. The Annual Flow Reduction was estimated using an Impact Factor of 39.5% for groundwater withdrawals and 100% for surface water withdrawals.
2. Maximum Monthly Reduction was estimated using a Seasonal Factor of 1.8.

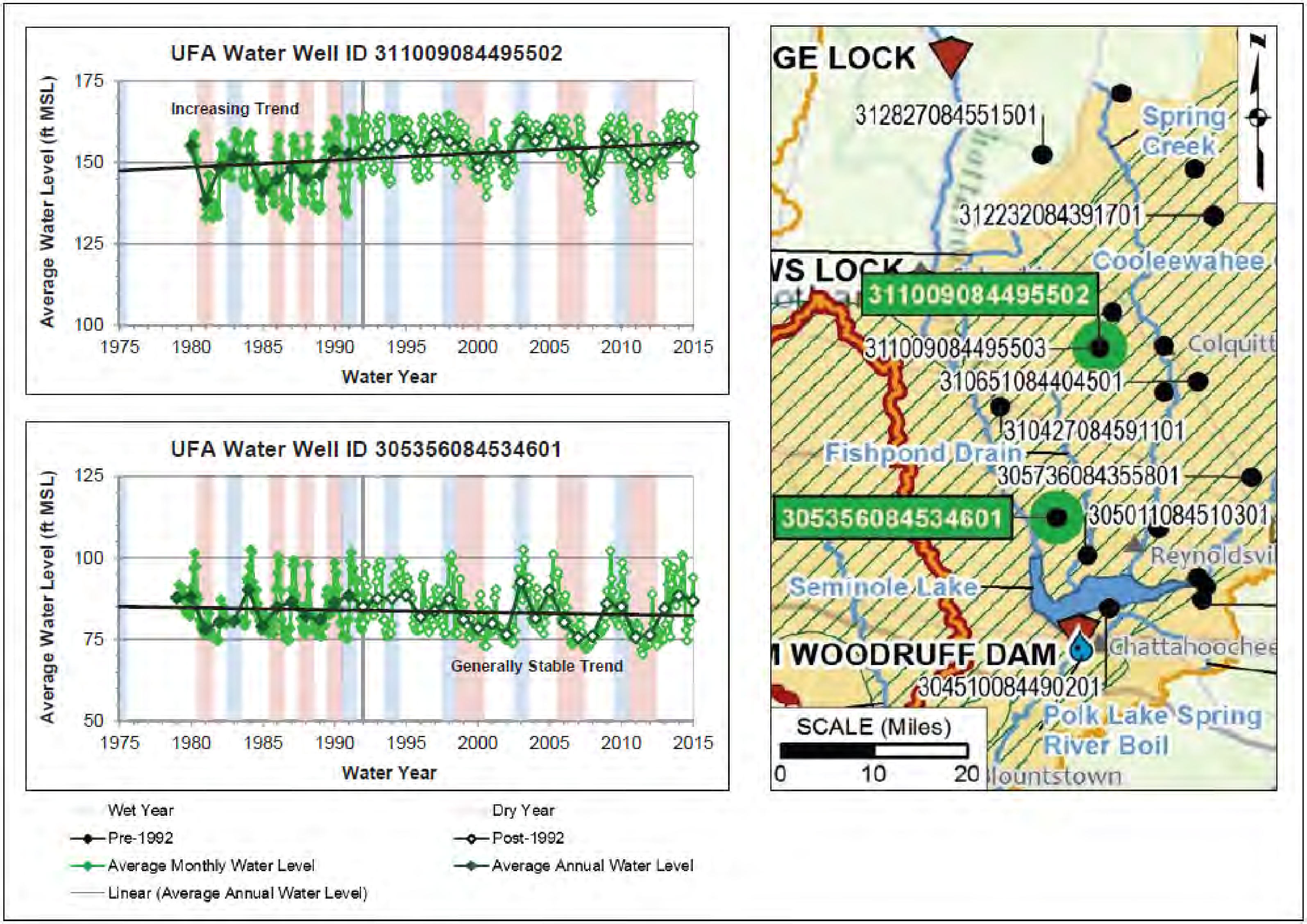
Panday Demo. 34 — Source: Panday Expert Report (GX-0873), 20 May 2016, Revised Table C-8, and Tables F-1 and F-2.



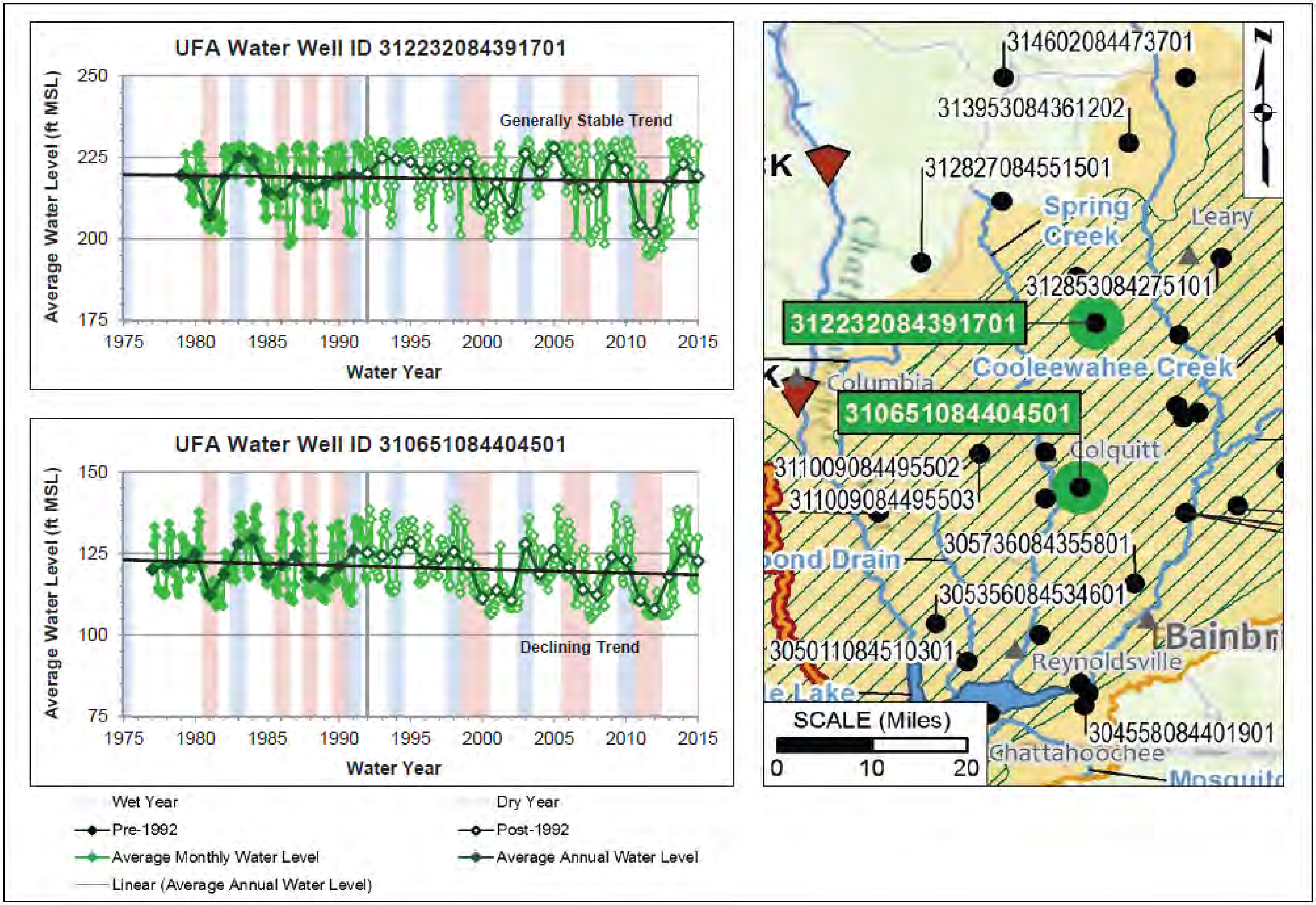
Trend Analysis for Select UFA Water Wells (1975-2015)

UFA Water Well ID	Results of Linear Trend Analaysis		Results of Mann-Kendall Statistical Trend Analysis
	Slope (feet/year)	Trend	
311009084495502	0.22	Increasing	Increasing
305356084534601	-0.07	Generally Stable	Stable
312232084391701	-0.04	Generally Stable	No Trend
310651084404501	-0.11	Declining	Stable
313808084093601	-0.01	Generally Stable	No Trend
312853084275101	-0.07	Generally Stable	Decreasing
314330084005402	-0.07	Generally Stable	Probably Decreasing
313521084051001	-0.11	Declining	Stable
313450084091801	0.07	Generally Stable	No Trend
313105084064302	-0.04	Generally Stable	Probably Decreasing
313031084005901	-0.4	Declining	Decreasing
313130084101001	-0.07	Generally Stable	Stable
312919084153801	-0.11	Declining	Stable
312704084071601	-0.07	Generally Stable	Probably Decreasing
312617084110701	-0.07	Generally Stable	Probably Decreasing
312127084065801	-0.26	Declining	Decreasing
311802084192302	-0.04	Generally Stable	Probably Decreasing
310507084262201	-0.11	Declining	Decreasing
310428084310501	-0.07	Generally Stable	Probably Decreasing
305736084355801	-0.07	Generally Stable	Decreasing

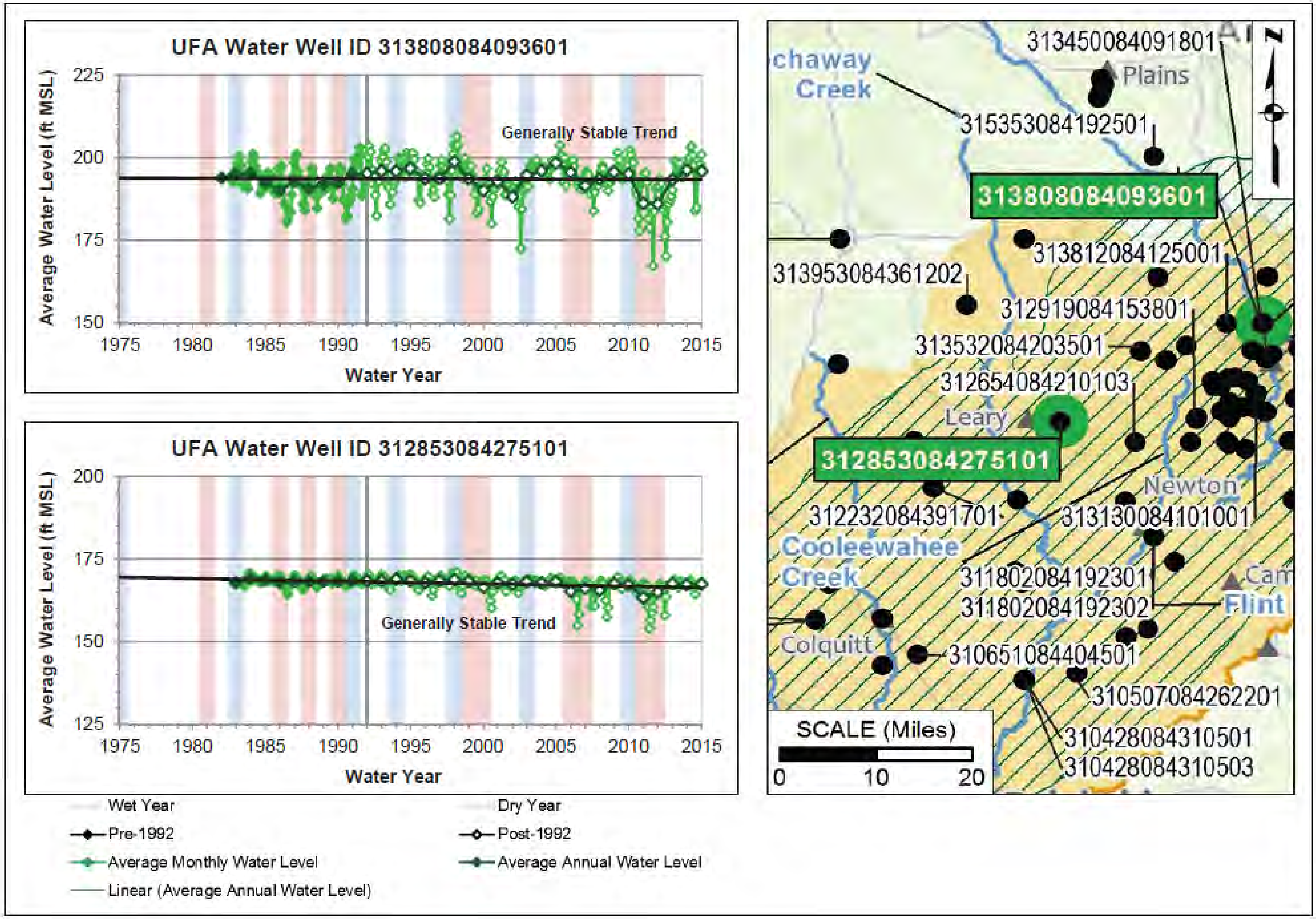
Panday Demo. 35a — Panday Expert Report (GX-0873), 20 May 2016, Fig. 5-4. Data was obtained from the USGS (JX-128). Groundwater level hydrographs are included with the Panday Demo. 35 attached to this testimony.



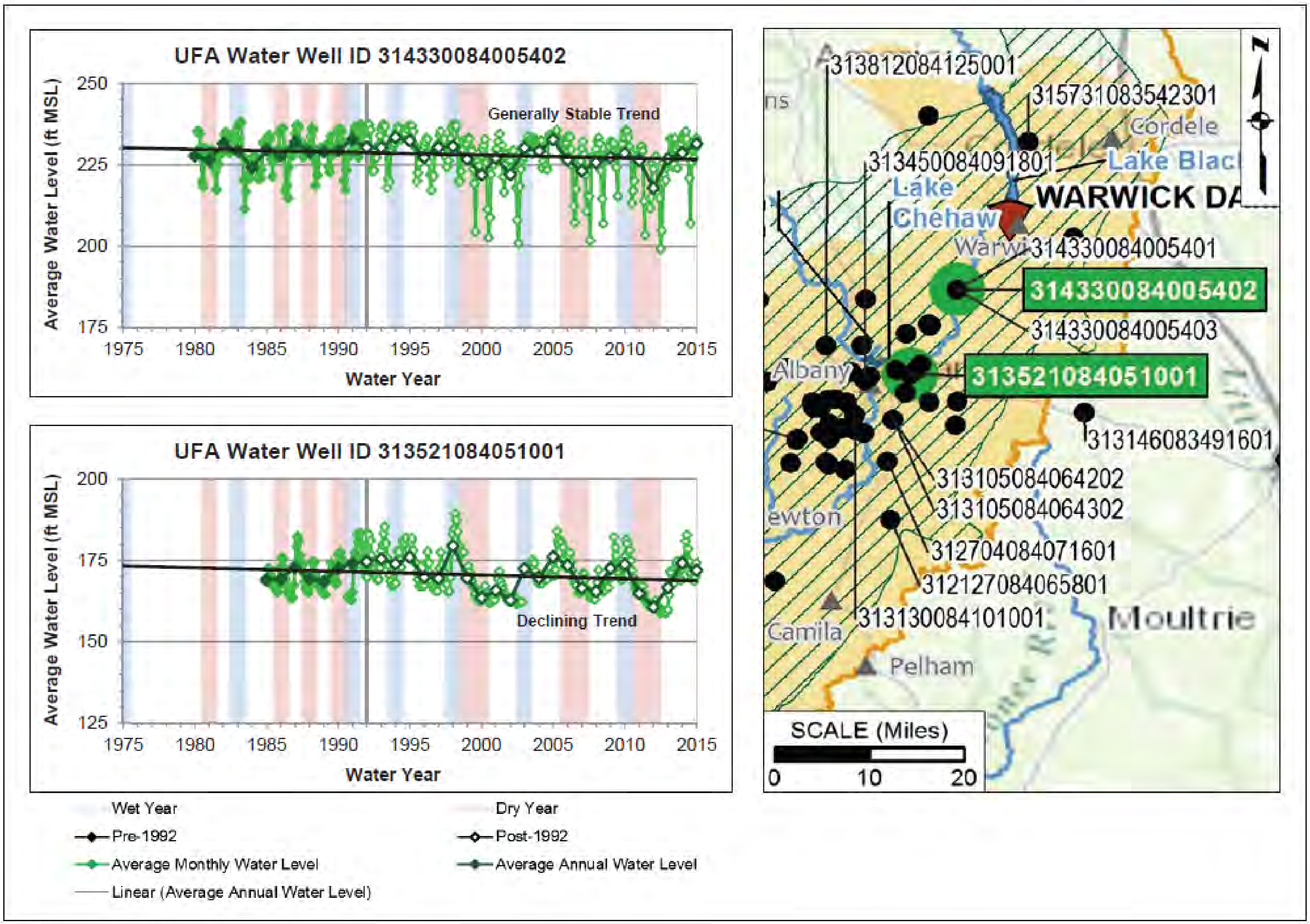
Panday Demo. 35b — Hydrographs for Select UFA Water Wells



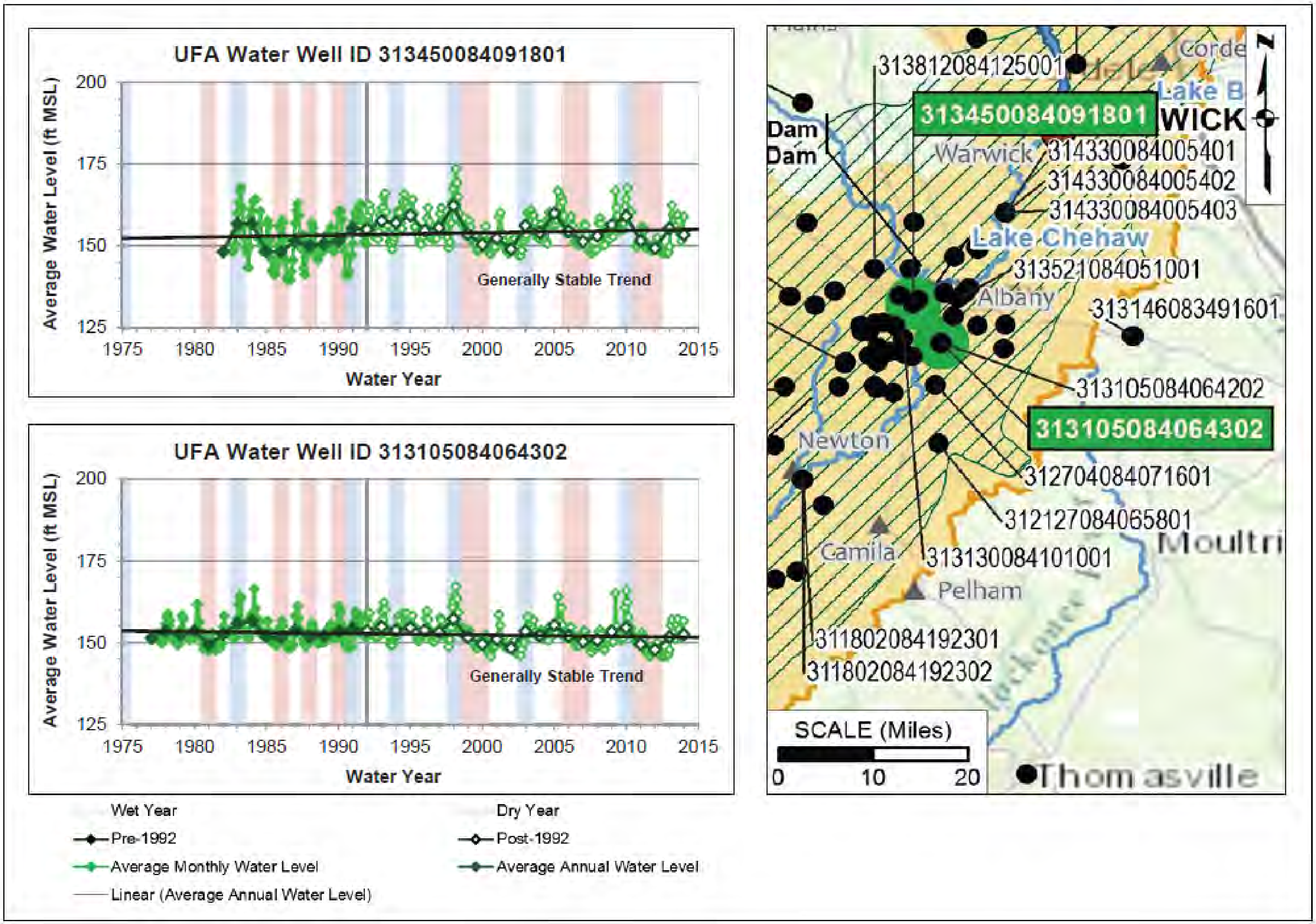
Panday Demo. 35c — Hydrographs for Select UFA Water Wells



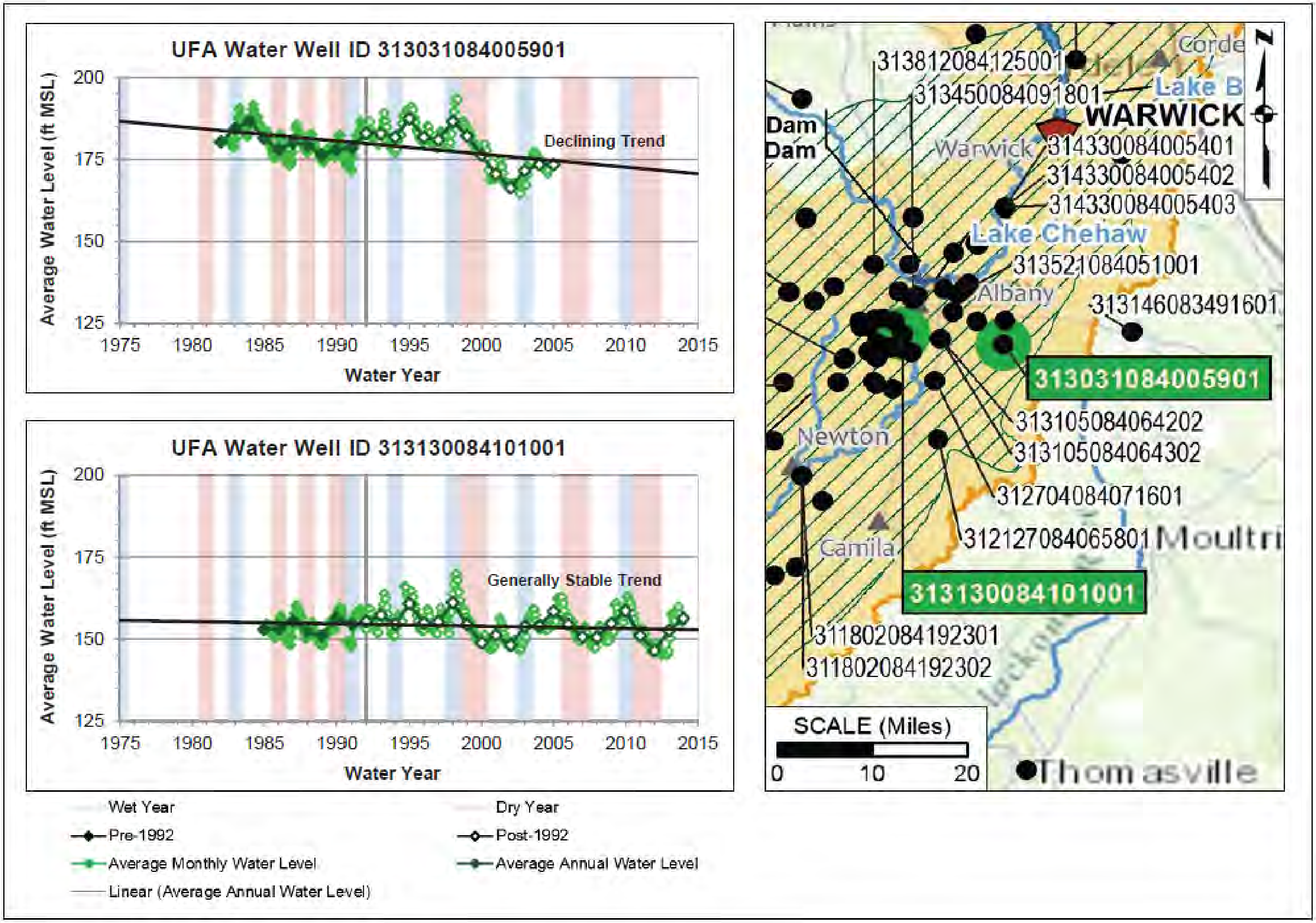
Panday Demo. 35d — Hydrographs for Select UFA Water Wells



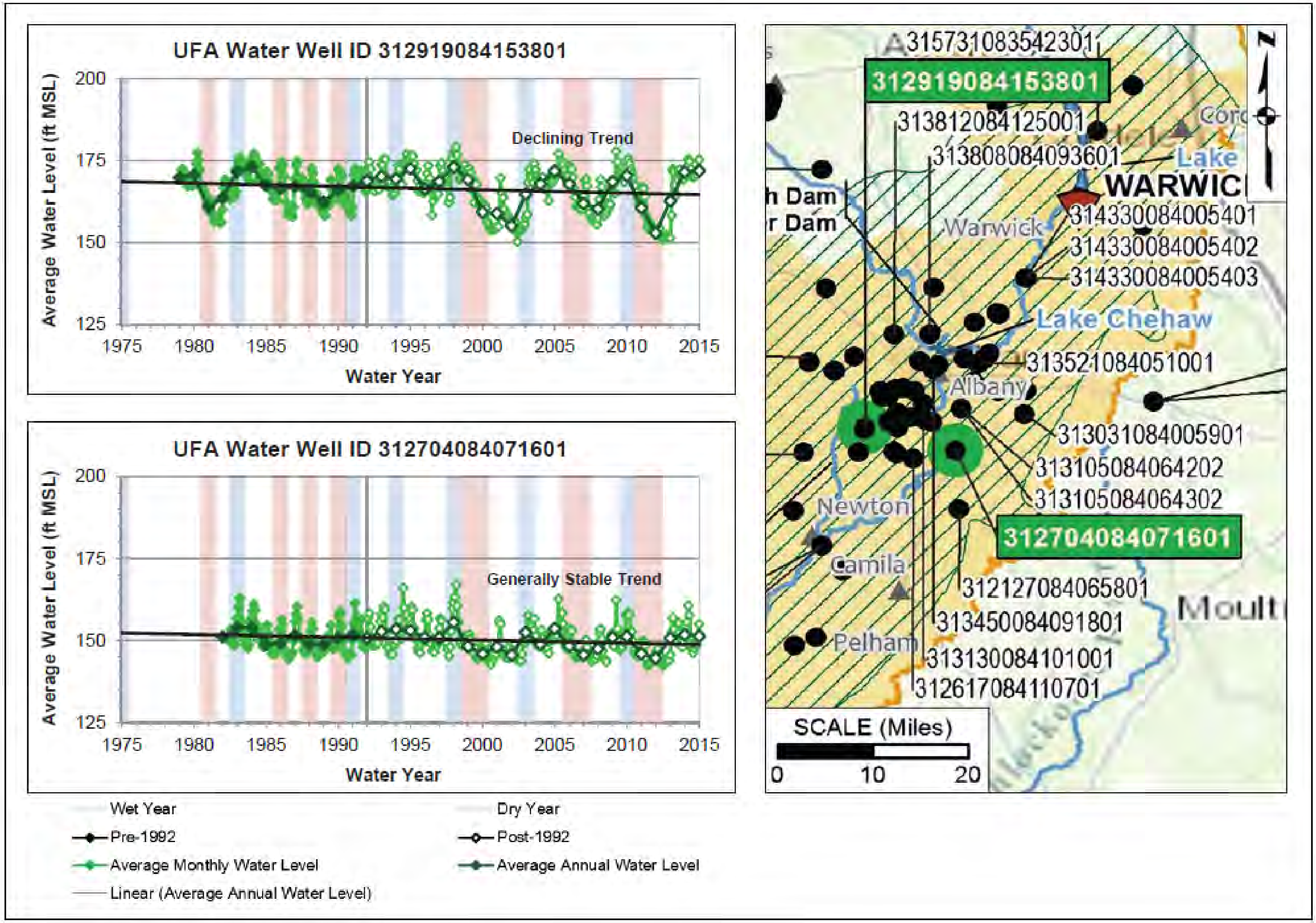
Panday Demo. 35e — Hydrographs for Select UFA Water Wells



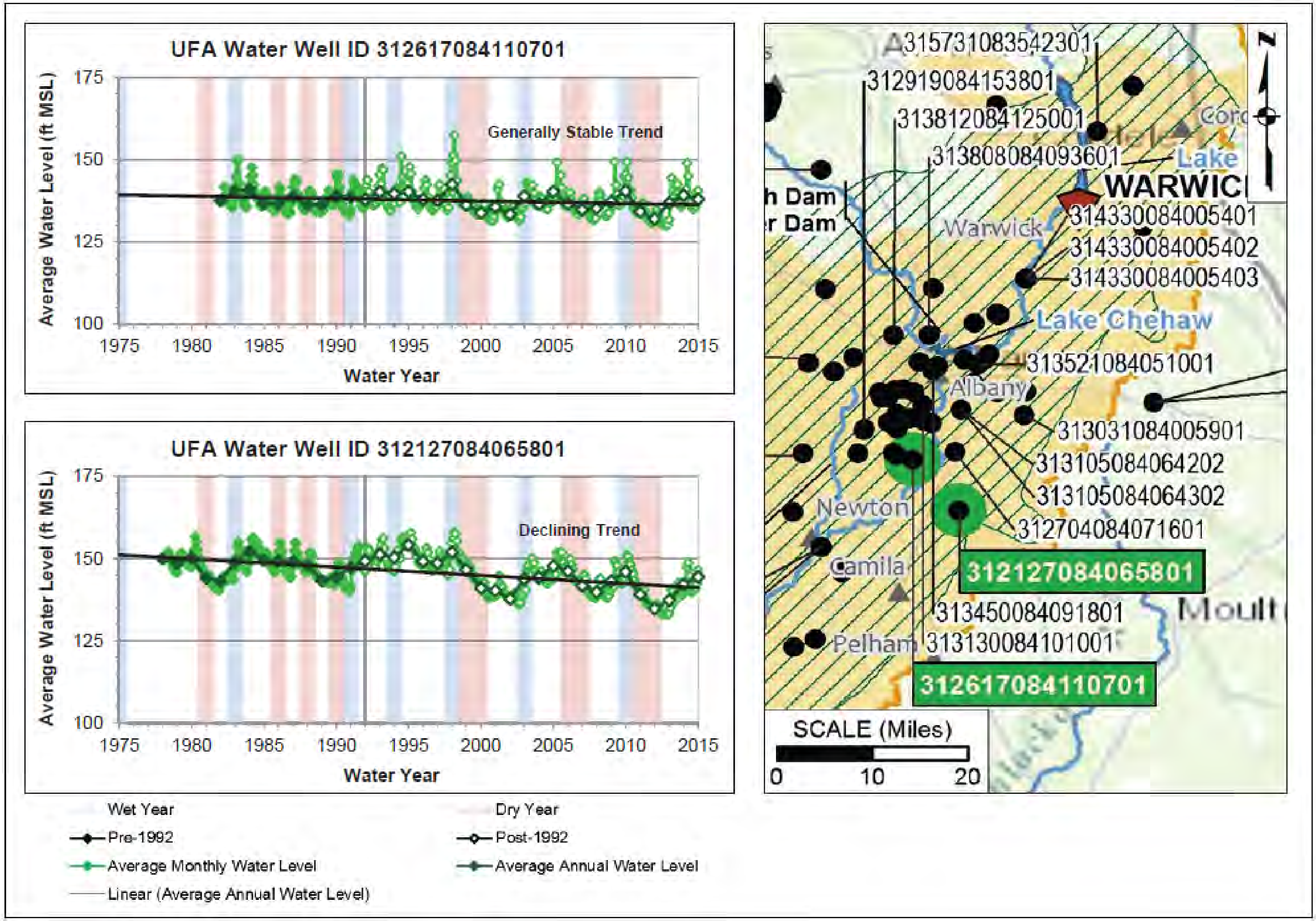
Panday Demo. 35f — Hydrographs for Select UFA Water Wells



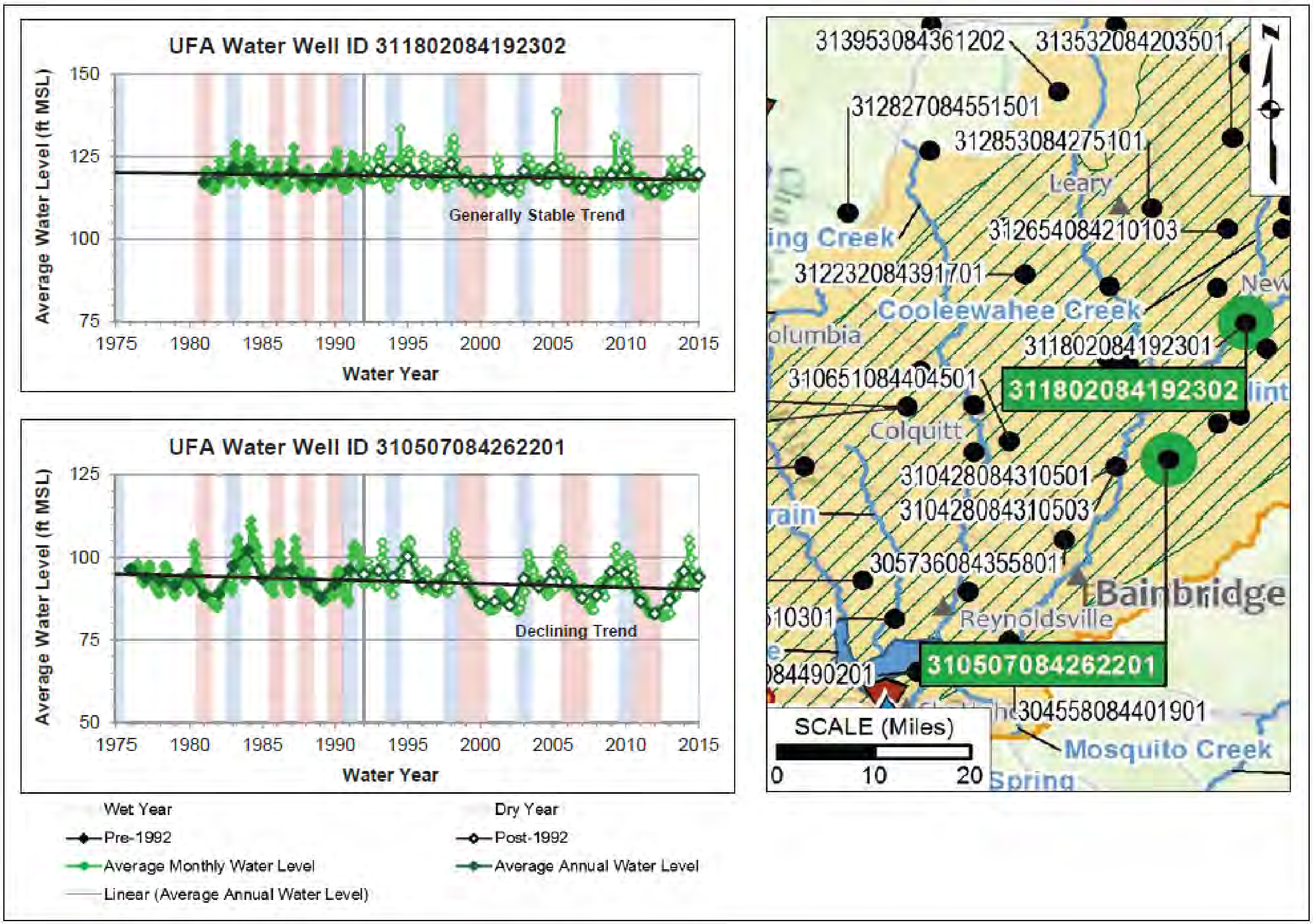
Panday Demo. 35g — Hydrographs for Select UFA Water Wells



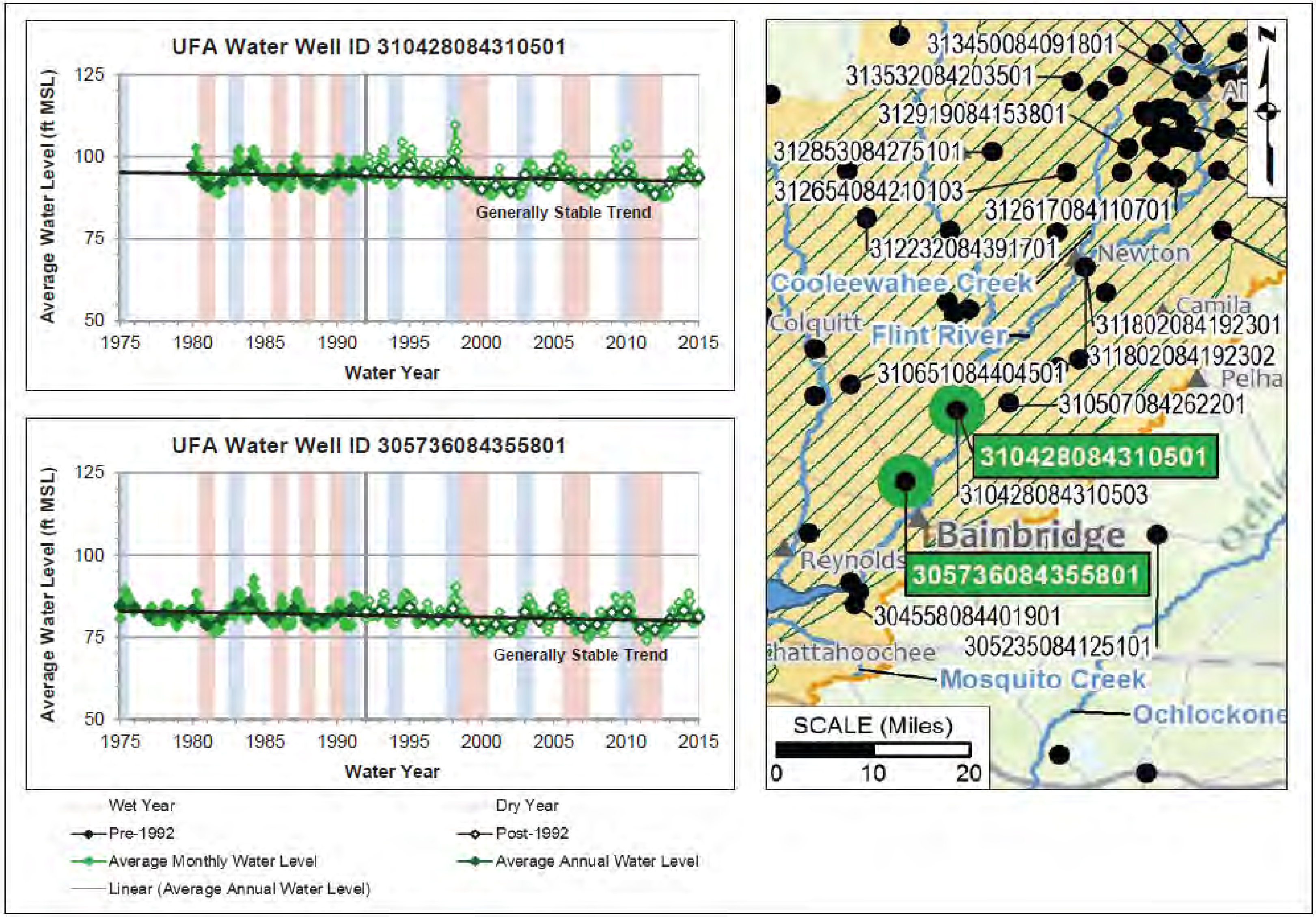
Panday Demo. 35h — Hydrographs for Select UFA Water Wells



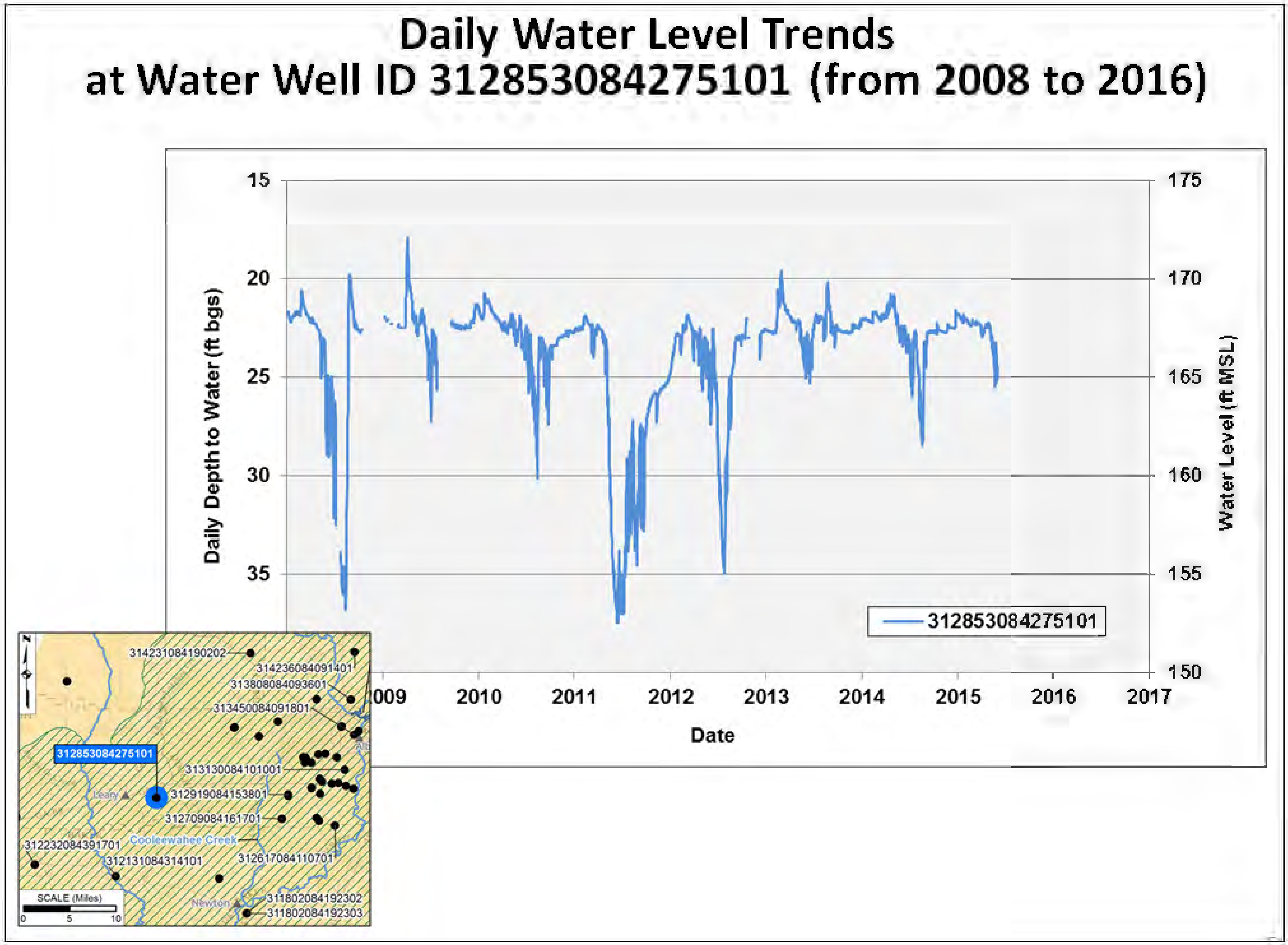
Panday Demo. 35i — Hydrographs for Select UFA Water Wells.



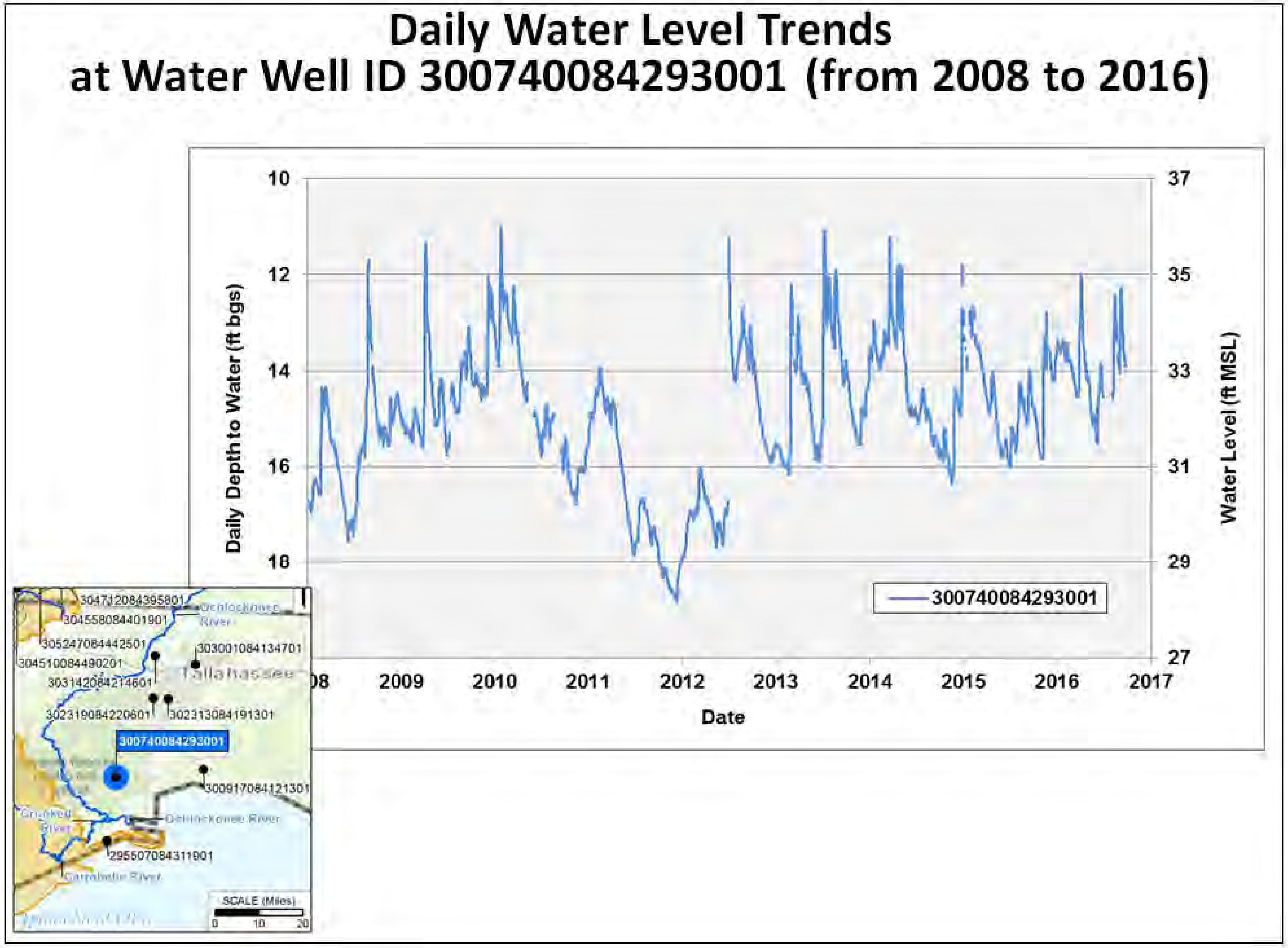
Panday Demo. 35j — Hydrographs for Select UFA Water Wells.



Panday Demo. 35k — Hydrographs for Select UFA Water Wells.

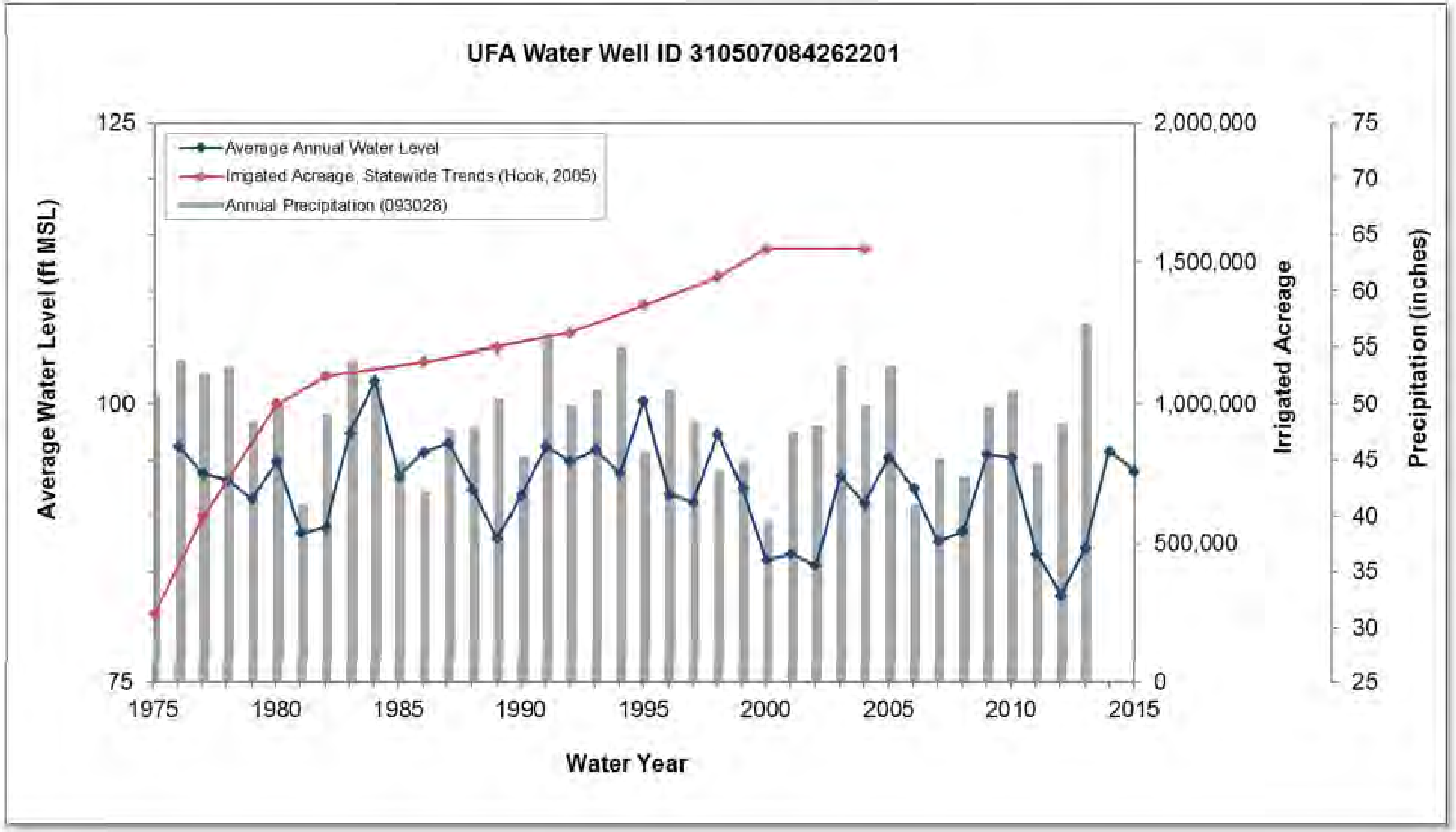


Panday Demo. 36 — Daily Water Level Trends for a UFA Monitoring Well in the Georgia portion of the Lower ACF River Basin (USGS Well ID 312853084275101) (JX-128).

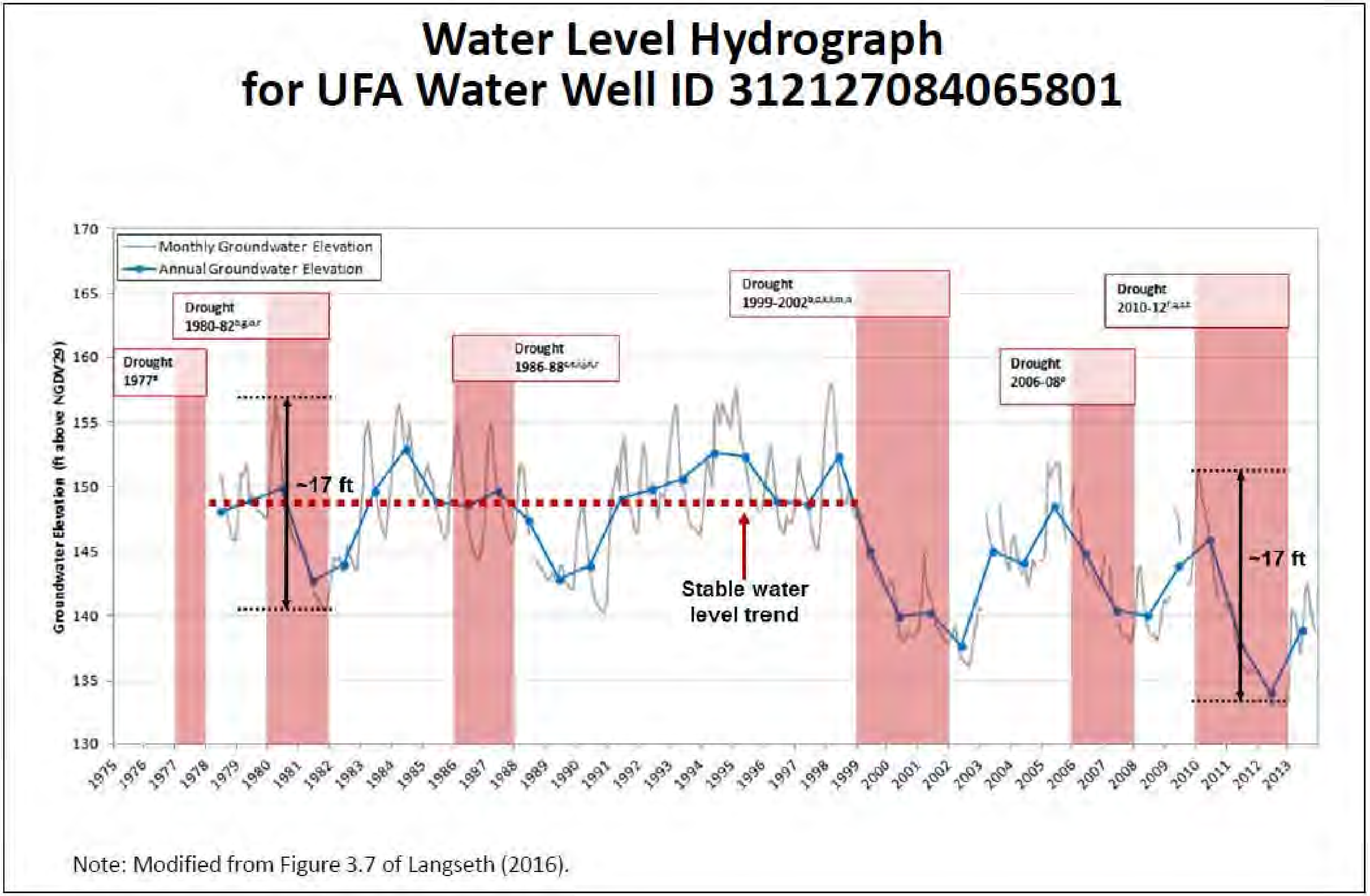


Panday Demo. 37 — Daily Water Level Trends for a UFA Monitoring Well near Crawfordville, Florida, Located just East of the Lower ACF River Basin (USGS well ID 300740084293001) (JX-128).

Trends in Irrigated Acreage, Precipitation, and Water Level Elevations at UFA Water Well ID 310507084262201 within the ACF River Basin



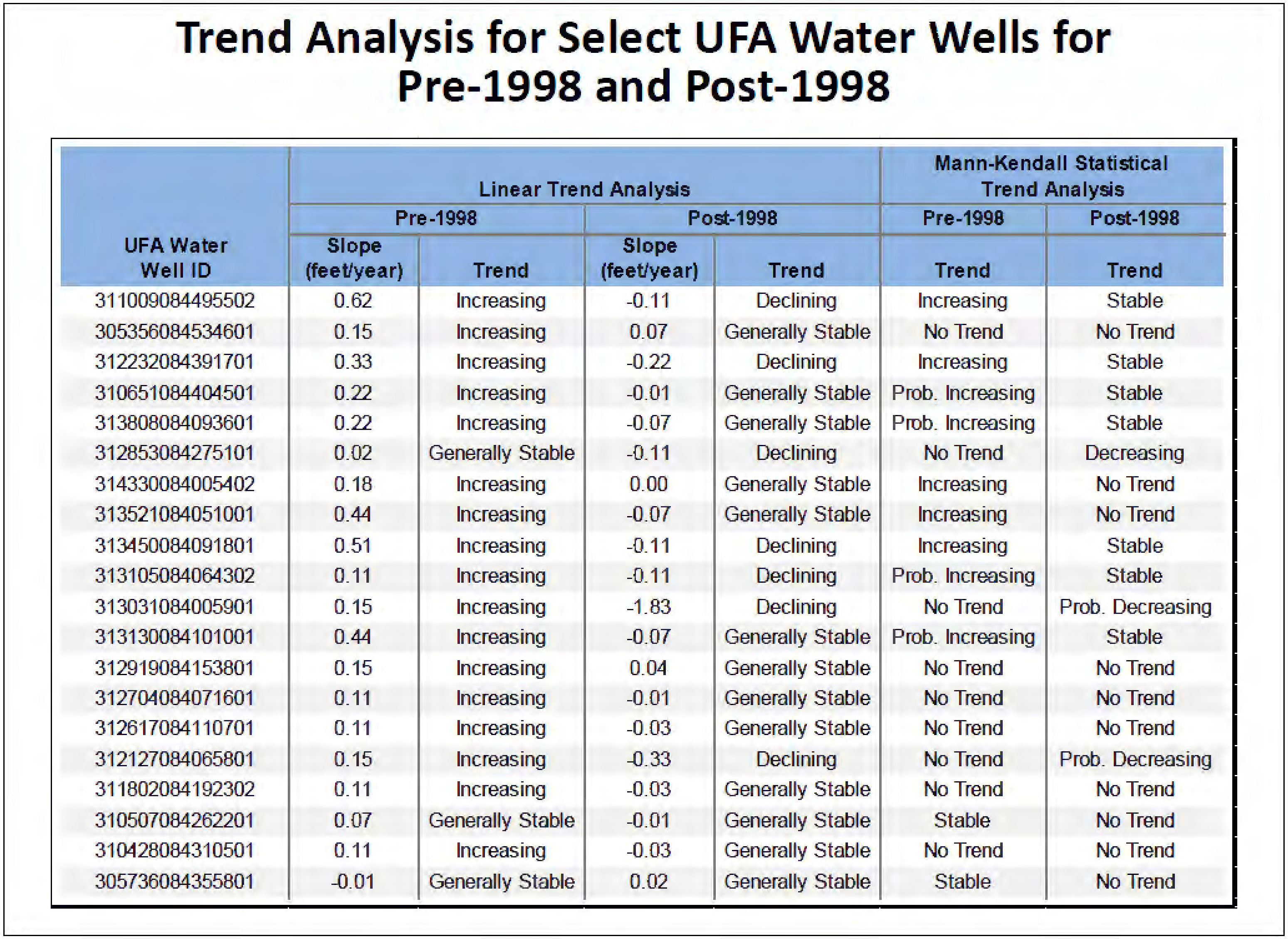
Panday Demo. 38 — This demonstrative shows the long-term growth of irrigated acreage in the State of Georgia and compares that trend with groundwater elevation and precipitation.



Water Level Hydrograph
for UFA Water Well ID 312127084065801

Note: Modified from Figure 3.7 of Langseth (2016).

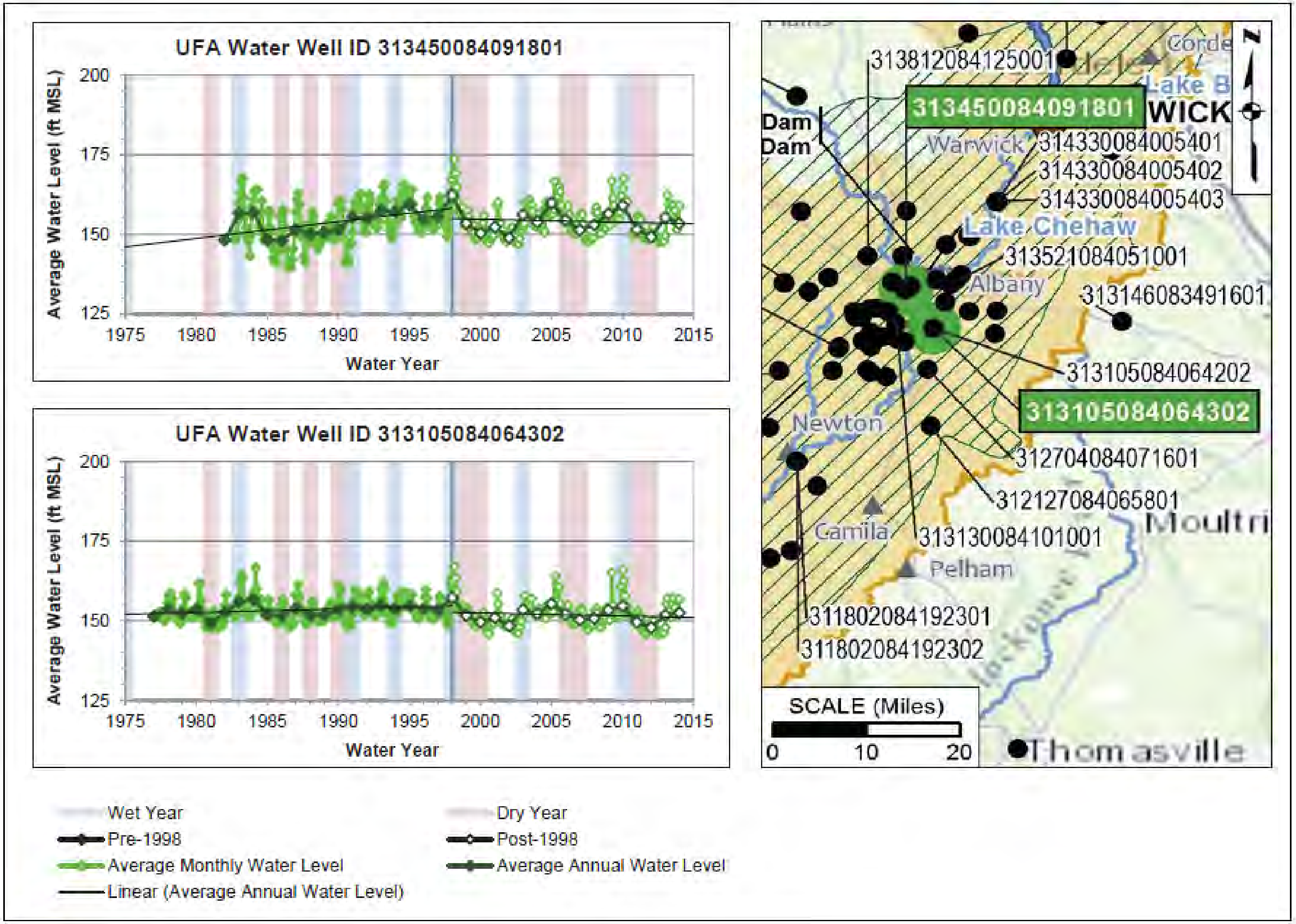
Panday Demo. 39 — Source: Panday Expert Report (GX-0873), 20 May 2016, Figure 6-2.



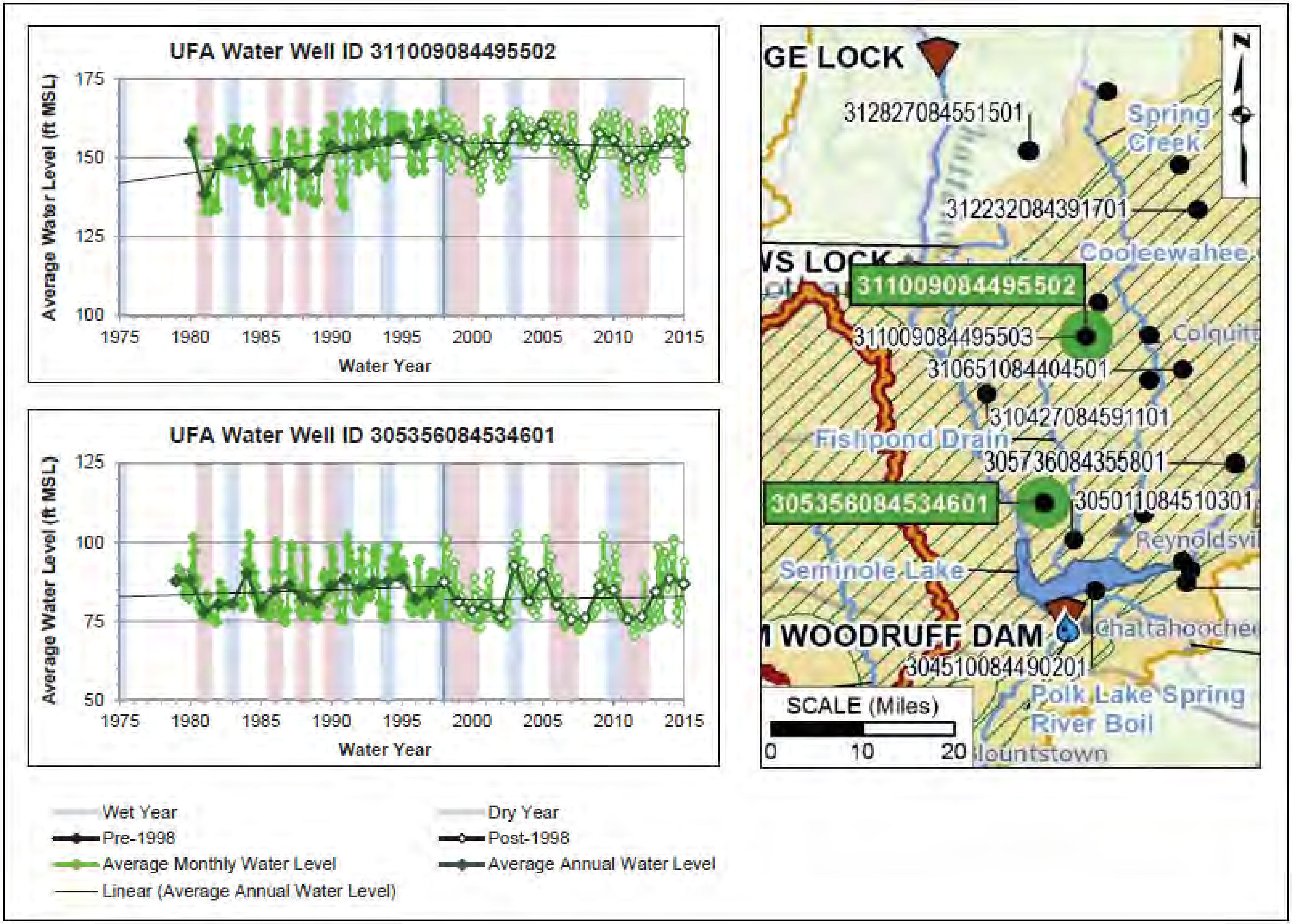
Trend Analysis for Select UFA Water Wells for Pre-1998 and Post-1998

UFA Water Well ID	Linear Trend Analysis				Mann-Kendall Statistical Trend Analysis	
	Pre-1998		Post-1998		Pre-1998	Post-1998
	Slope (feet/year)	Trend	Slope (feet/year)	Trend	Trend	Trend
311009084495502	0.62	Increasing	-0.11	Declining	Increasing	Stable
305356084534601	0.15	Increasing	0.07	Generally Stable	No Trend	No Trend
312232084391701	0.33	Increasing	-0.22	Declining	Increasing	Stable
310651084404501	0.22	Increasing	-0.01	Generally Stable	Prob. Increasing	Stable
313808084093601	0.22	Increasing	-0.07	Generally Stable	Prob. Increasing	Stable
312853084275101	0.02	Generally Stable	-0.11	Declining	No Trend	Decreasing
314330084005402	0.18	Increasing	0.00	Generally Stable	Increasing	No Trend
313521084051001	0.44	Increasing	-0.07	Generally Stable	Increasing	No Trend
313450084091801	0.51	Increasing	-0.11	Declining	Increasing	Stable
313105084064302	0.11	Increasing	-0.11	Declining	Prob. Increasing	Stable
313031084005901	0.15	Increasing	-1.83	Declining	No Trend	Prob. Decreasing
313130084101001	0.44	Increasing	-0.07	Generally Stable	Prob. Increasing	Stable
312919084153801	0.15	Increasing	0.04	Generally Stable	No Trend	No Trend
312704084071601	0.11	Increasing	-0.01	Generally Stable	No Trend	No Trend
312617084110701	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
312127084065801	0.15	Increasing	-0.33	Declining	No Trend	Prob. Decreasing
311802084192302	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
310507084262201	0.07	Generally Stable	-0.01	Generally Stable	Stable	No Trend
310428084310501	0.11	Increasing	-0.03	Generally Stable	No Trend	No Trend
305736084355801	-0.01	Generally Stable	0.02	Generally Stable	Stable	No Trend

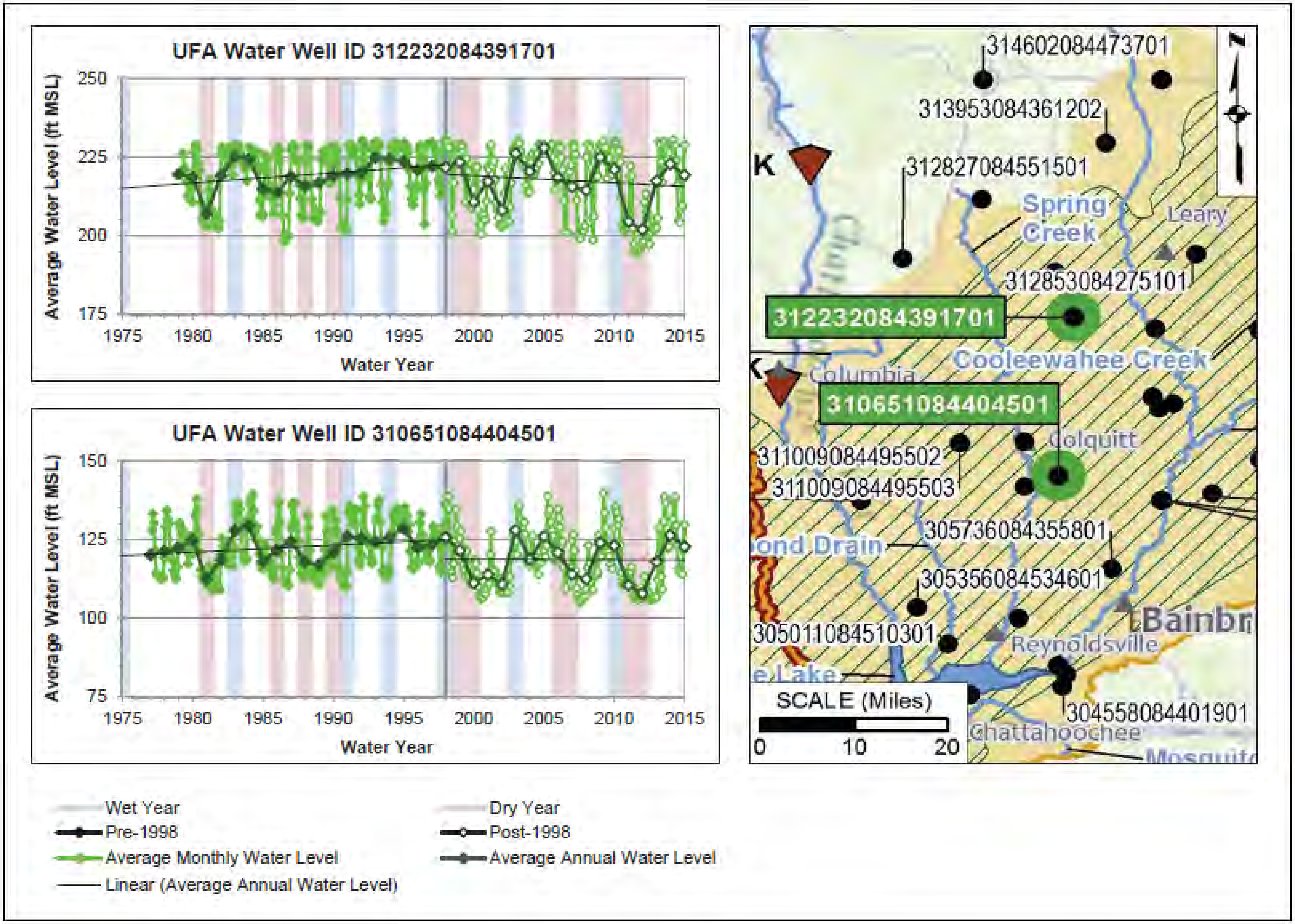
Panday Demo. 40 — Shows trend analysis for select UFA water wells for pre-1998 and post-1998. Data was obtained from the USGS (JX-128). Groundwater level hydrographs are included with the Panday Demo. 40 attached to this testimony.



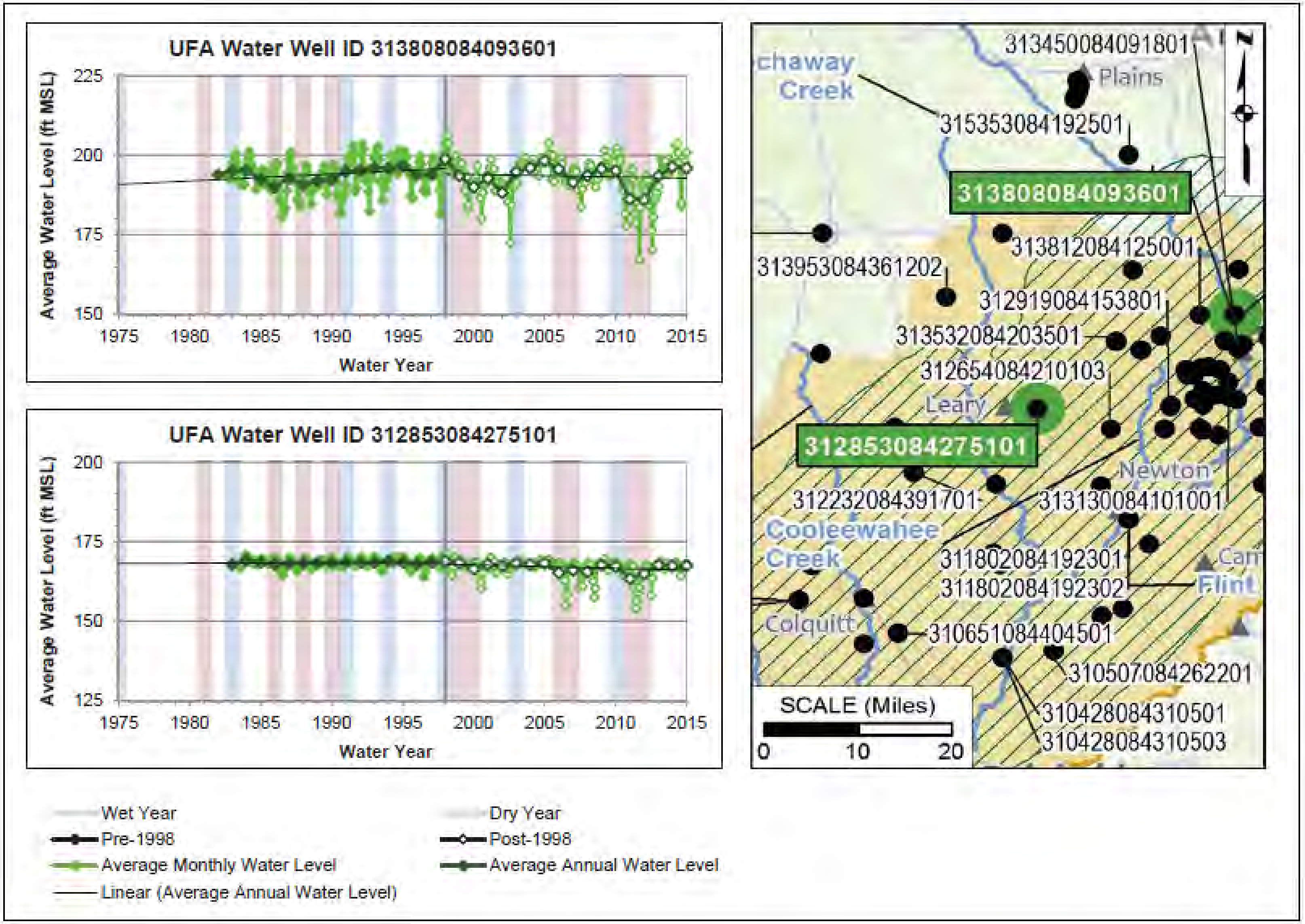
Panday Demo. 41a — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24.
Data was obtained from the USGS (JX-128).



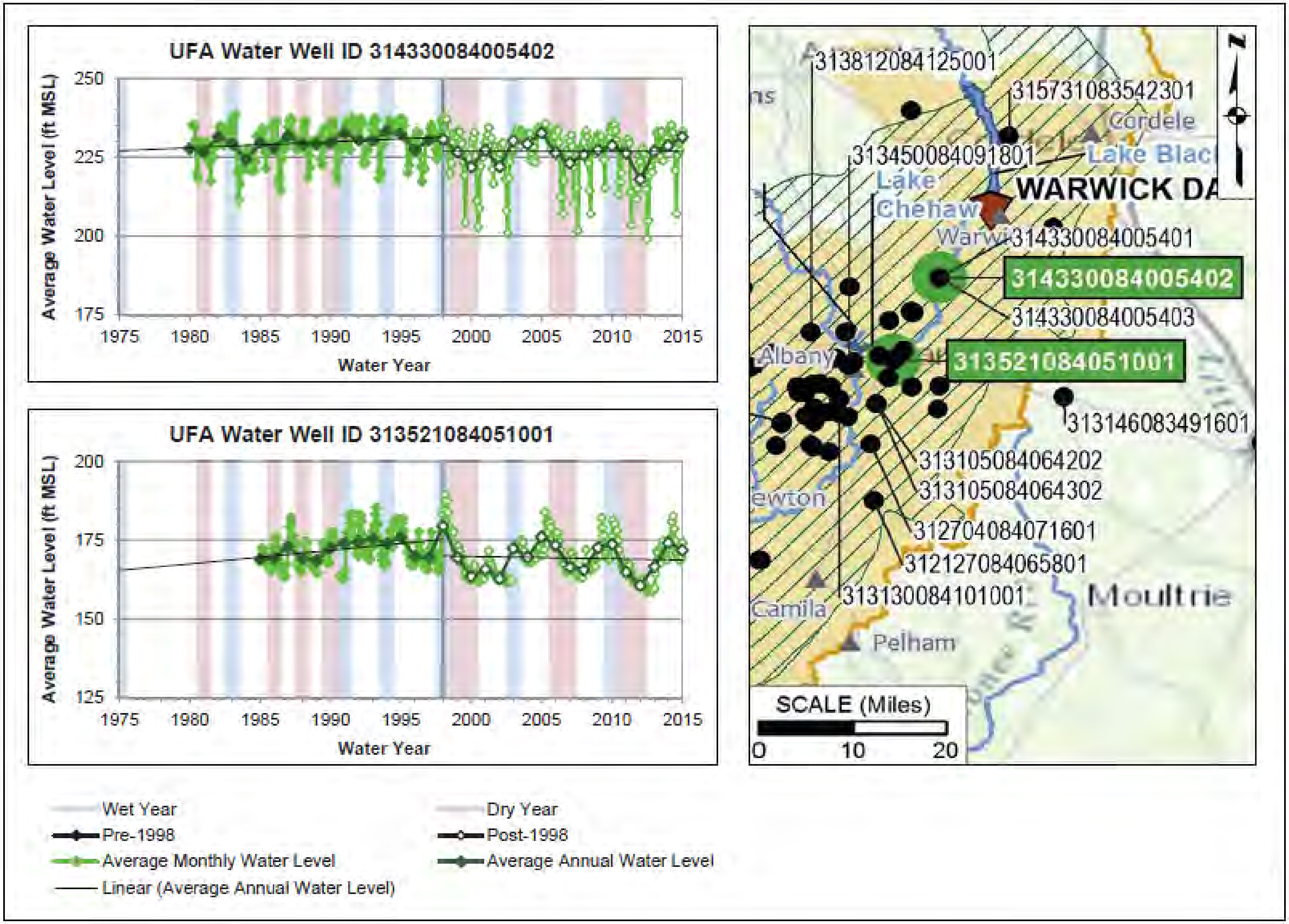
Panday Demo. 41b — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).



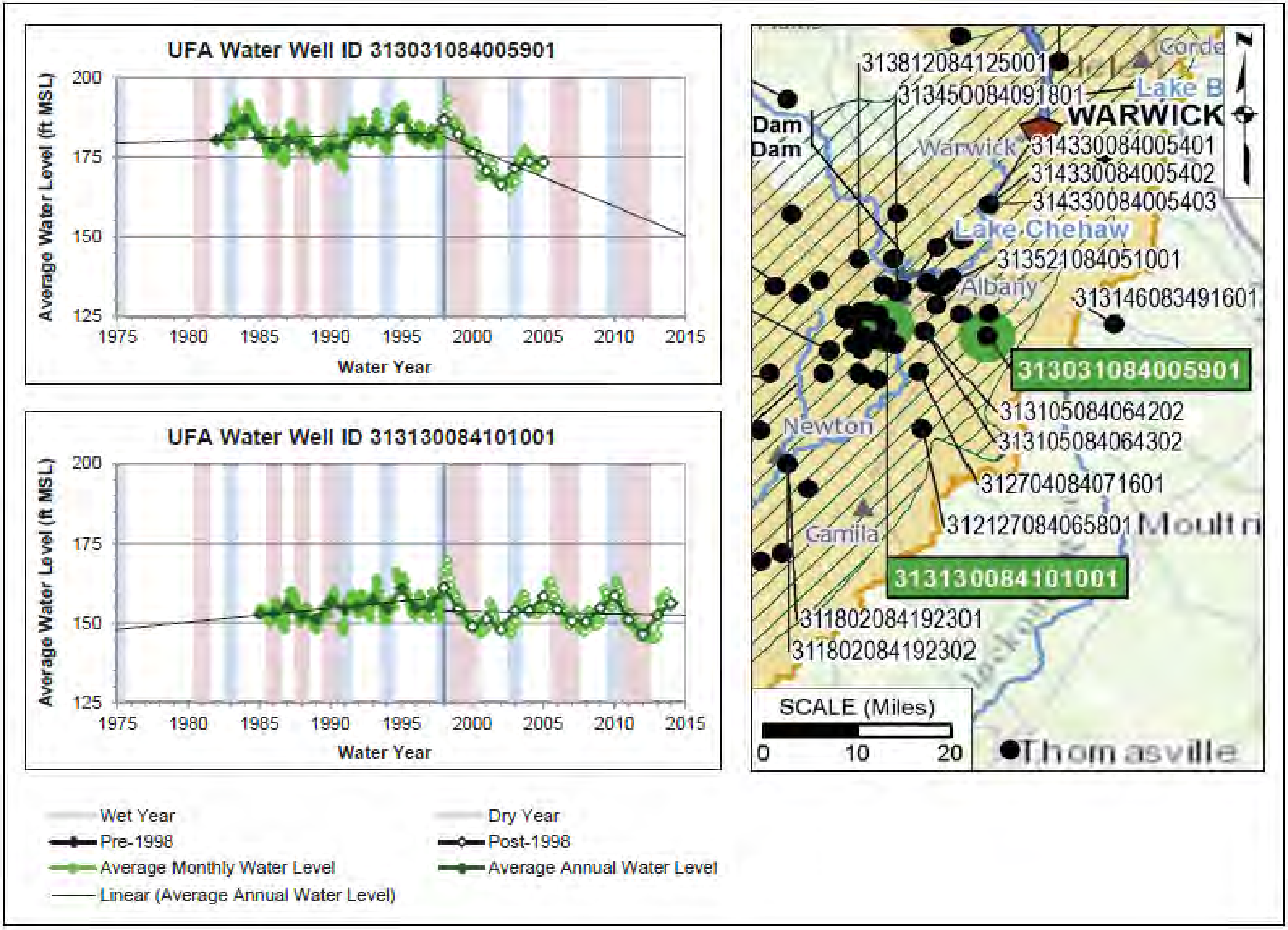
Panday Demo. 41c — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).



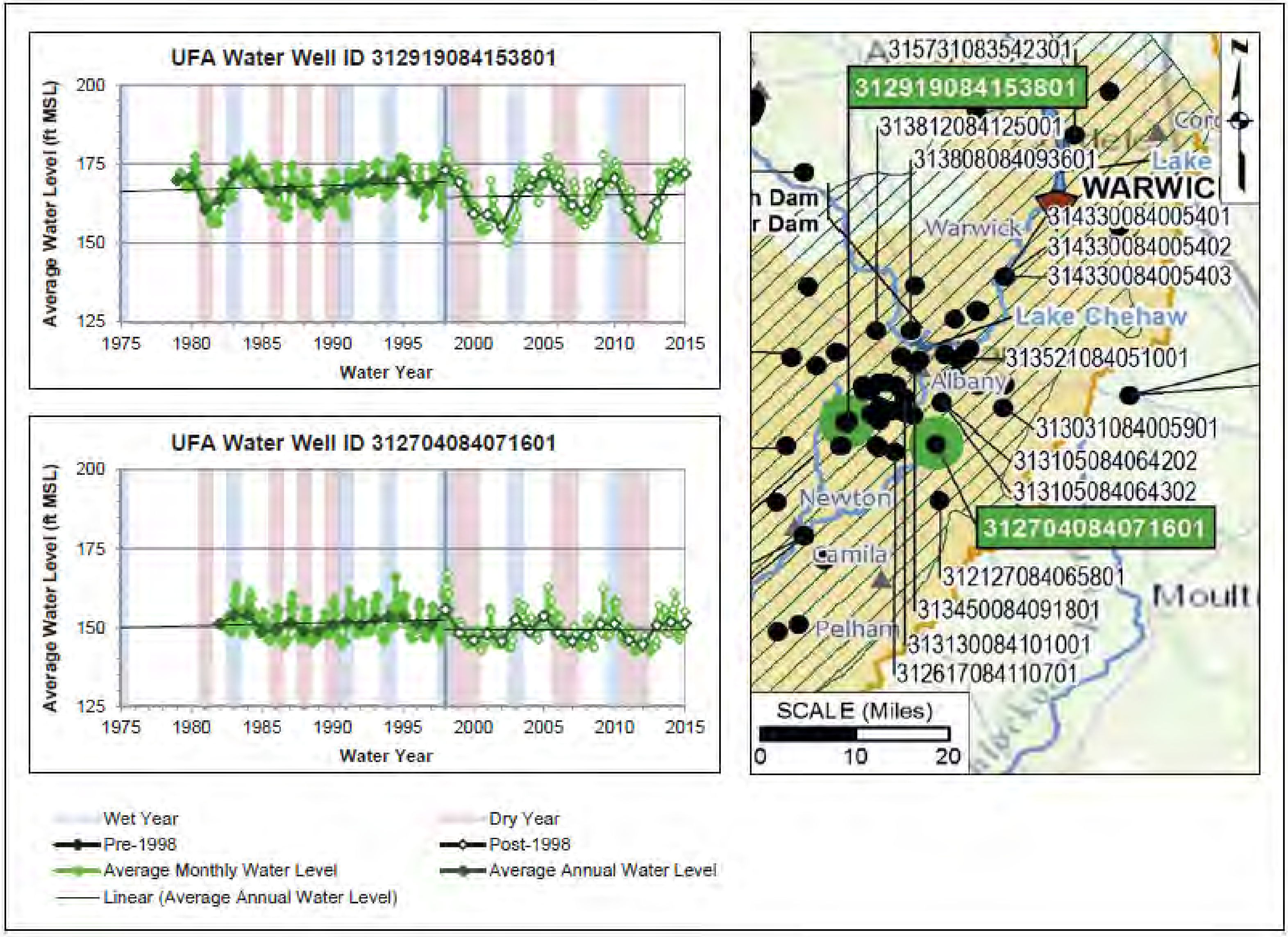
Panday Demo. 41d — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).



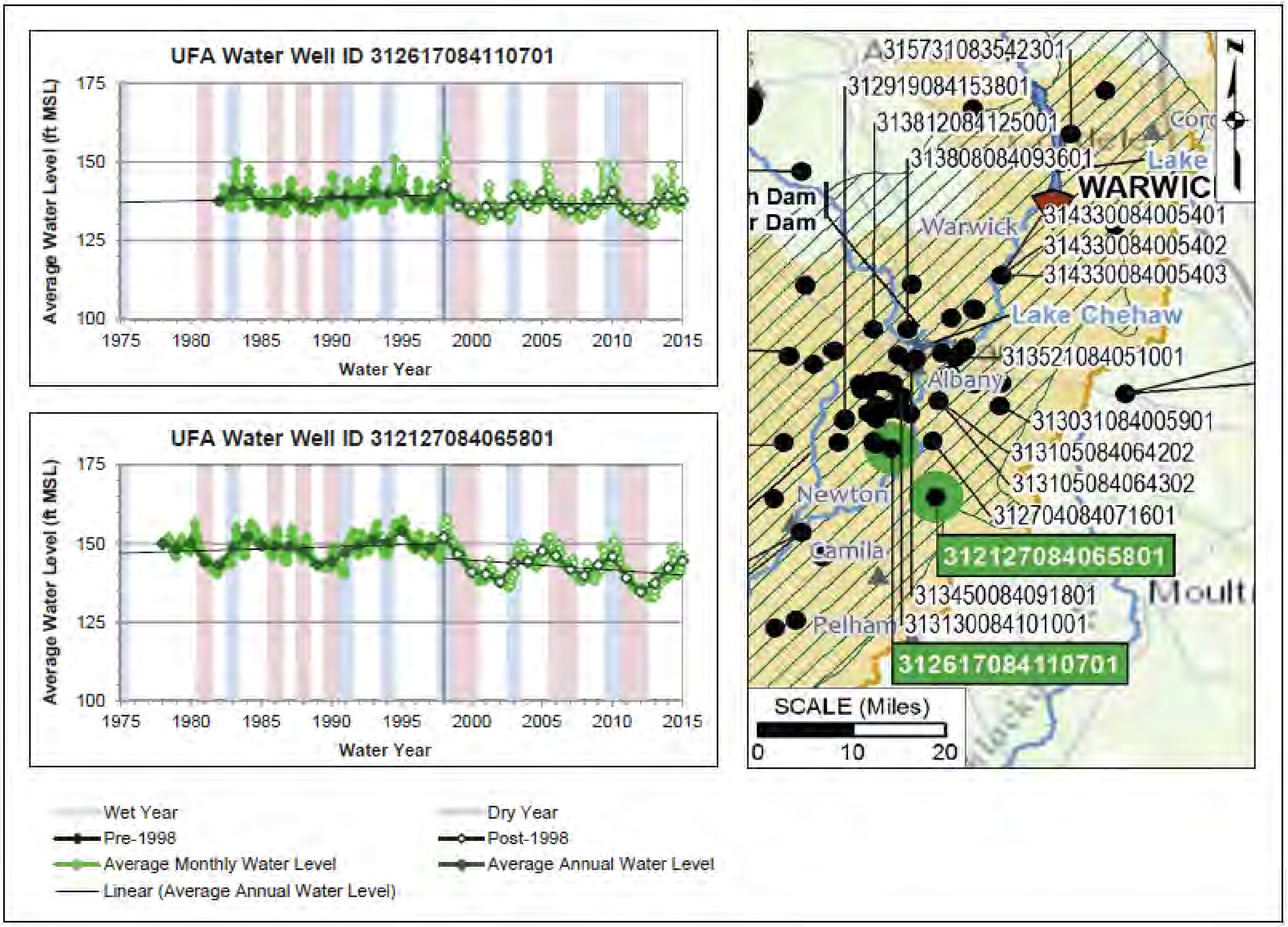
Panday Demo. 41e — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).



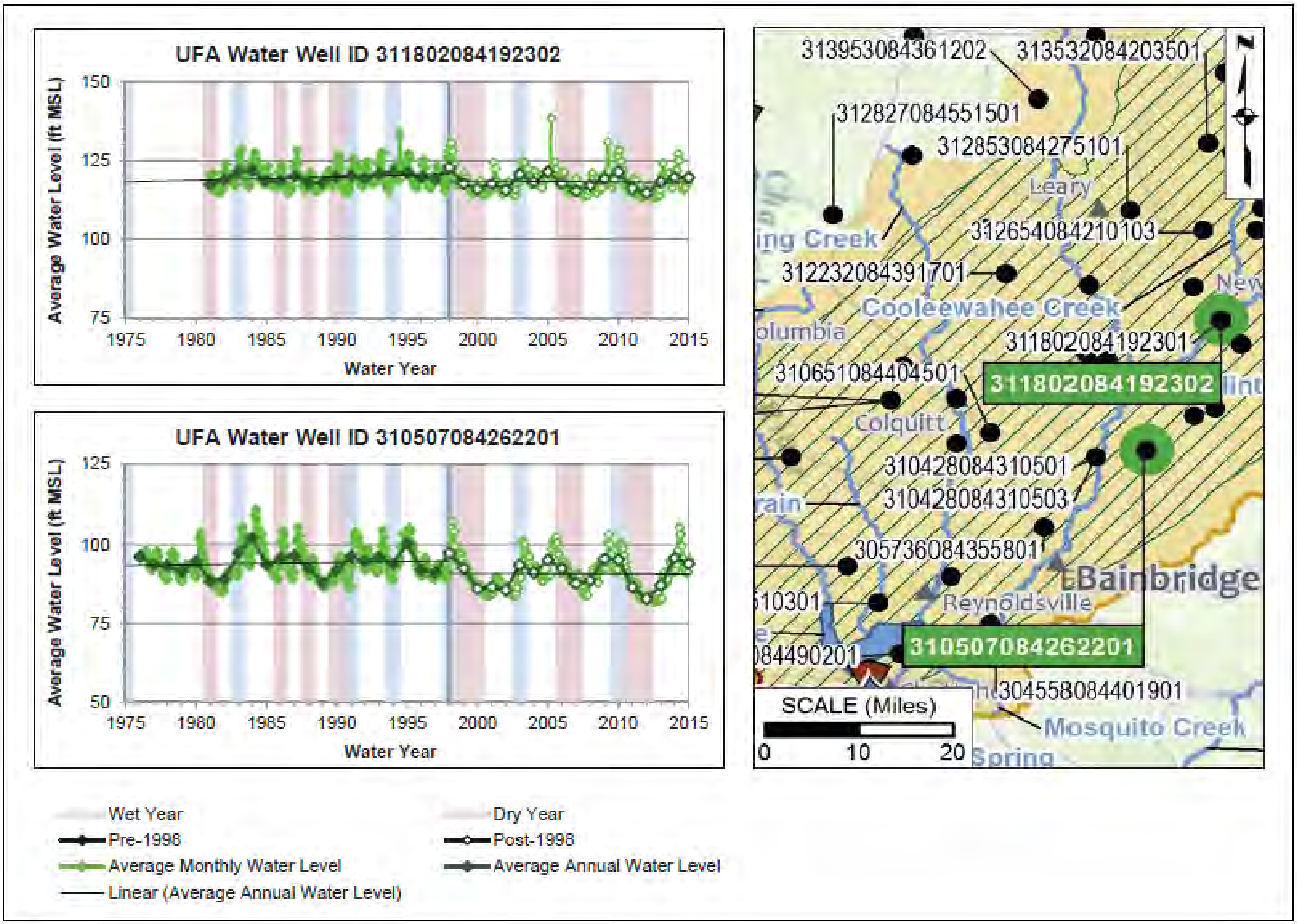
Panday Demo. 41f — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24.
Data was obtained from the USGS (JX-128).



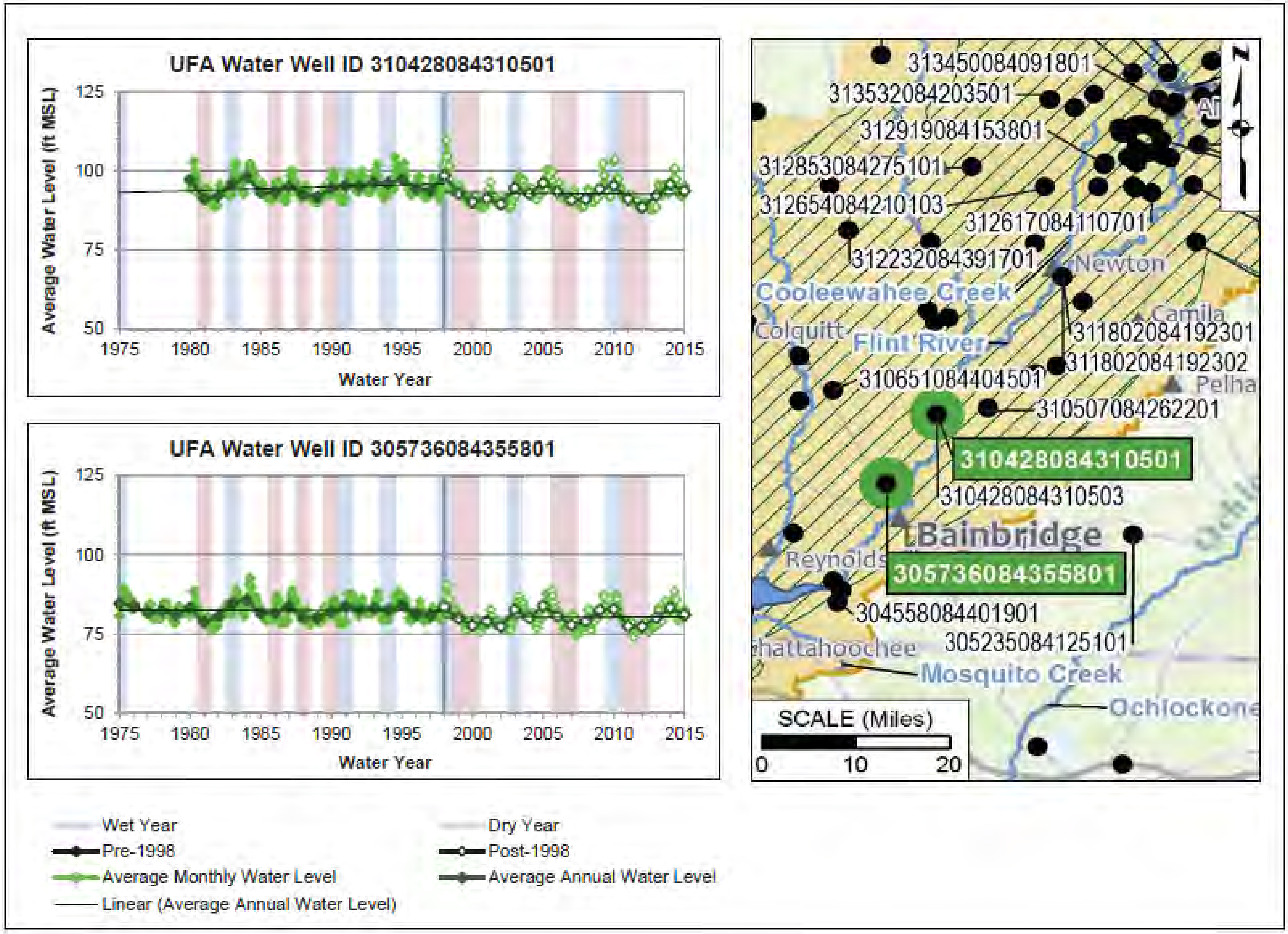
**Panday Demo. 41g — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24.
Data was obtained from the USGS (JX-128).**



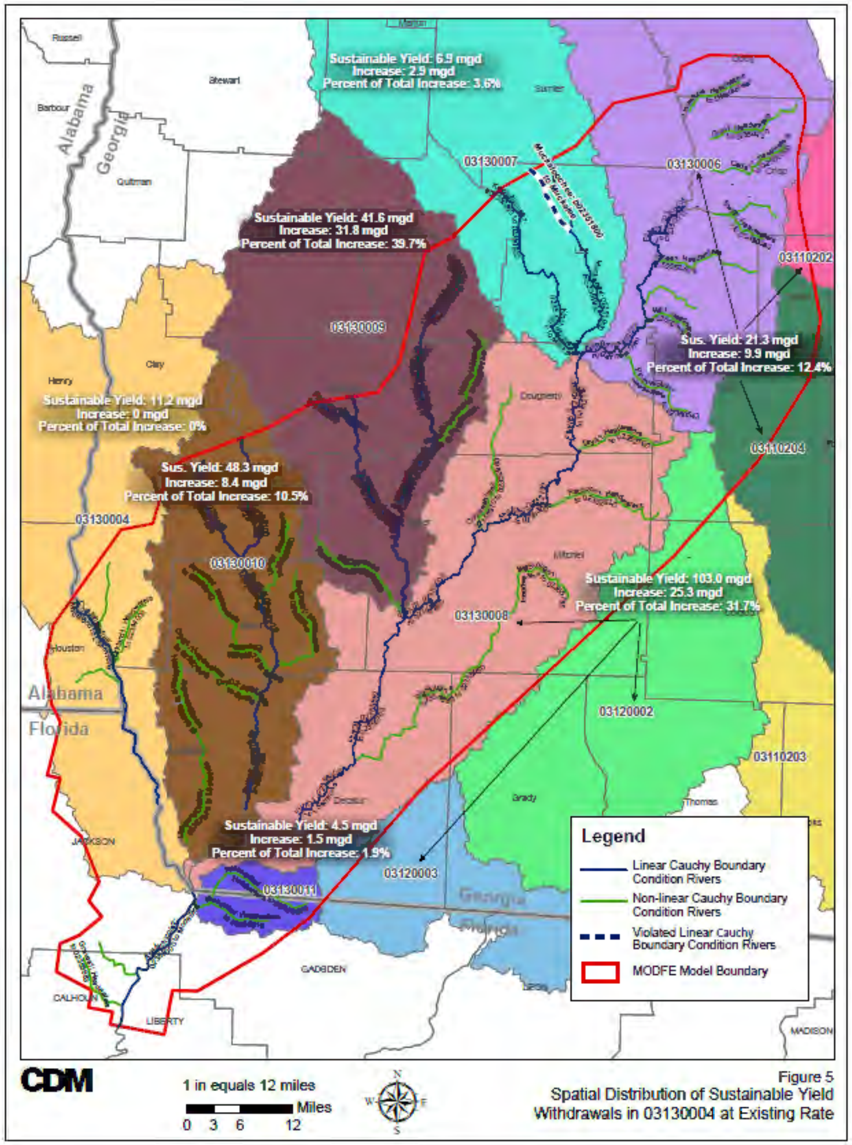
Panday Demo. 41h — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24. Data was obtained from the USGS (JX-128).



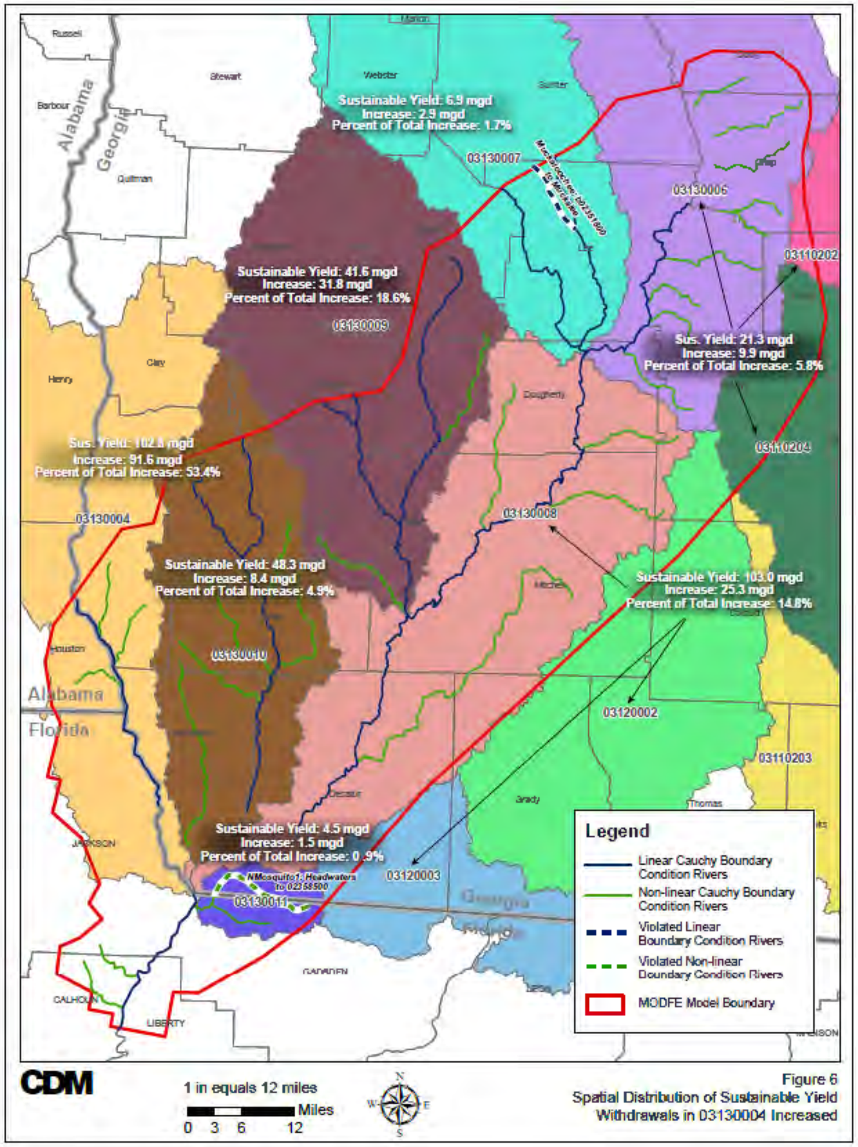
Panday Demo. 41i — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24.
Data was obtained from the USGS (JX-128).



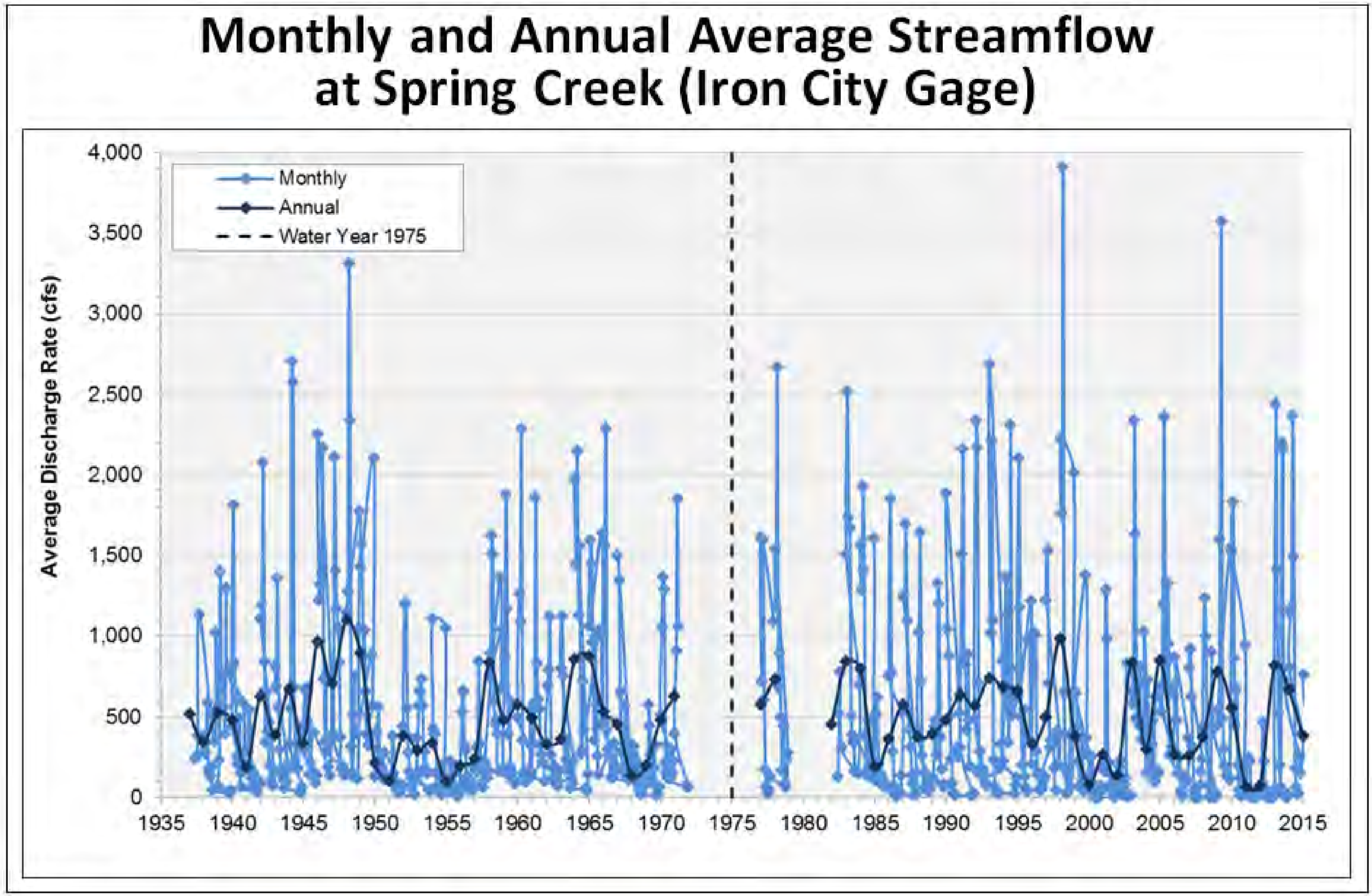
Panday Demo. 41j — Modified from Panday Expert Report (GX-0873), 20 May 2016, Fig.C-24.
Data was obtained from the USGS (JX-128).



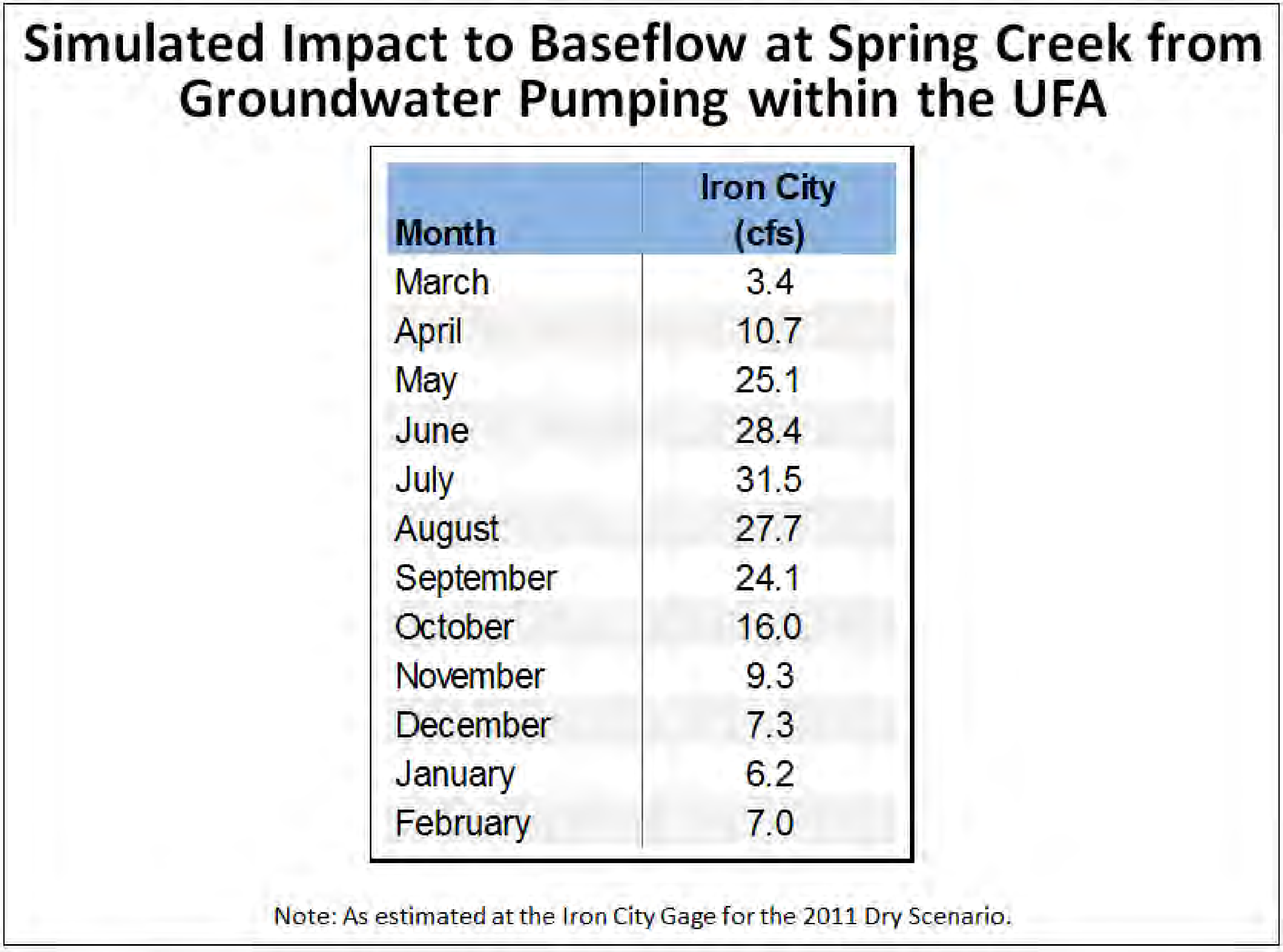
Panday Demo. 42 — Technical Memorandum on Dougherty Plain Sustainable Yield Groundwater Model (CDM 2012 Figure. 5) (JX-057).



Panday Demo. 43 — Technical Memorandum on Dougherty Plain Sustainable Yield Groundwater Model (CDM 2012 Figure. 6) (JX-057).



Panday Demo. 44 — Panday Expert Report (GX-0873), 20 May 2016, Fig. F-5.
Data was obtained from the USGS (JX-128).

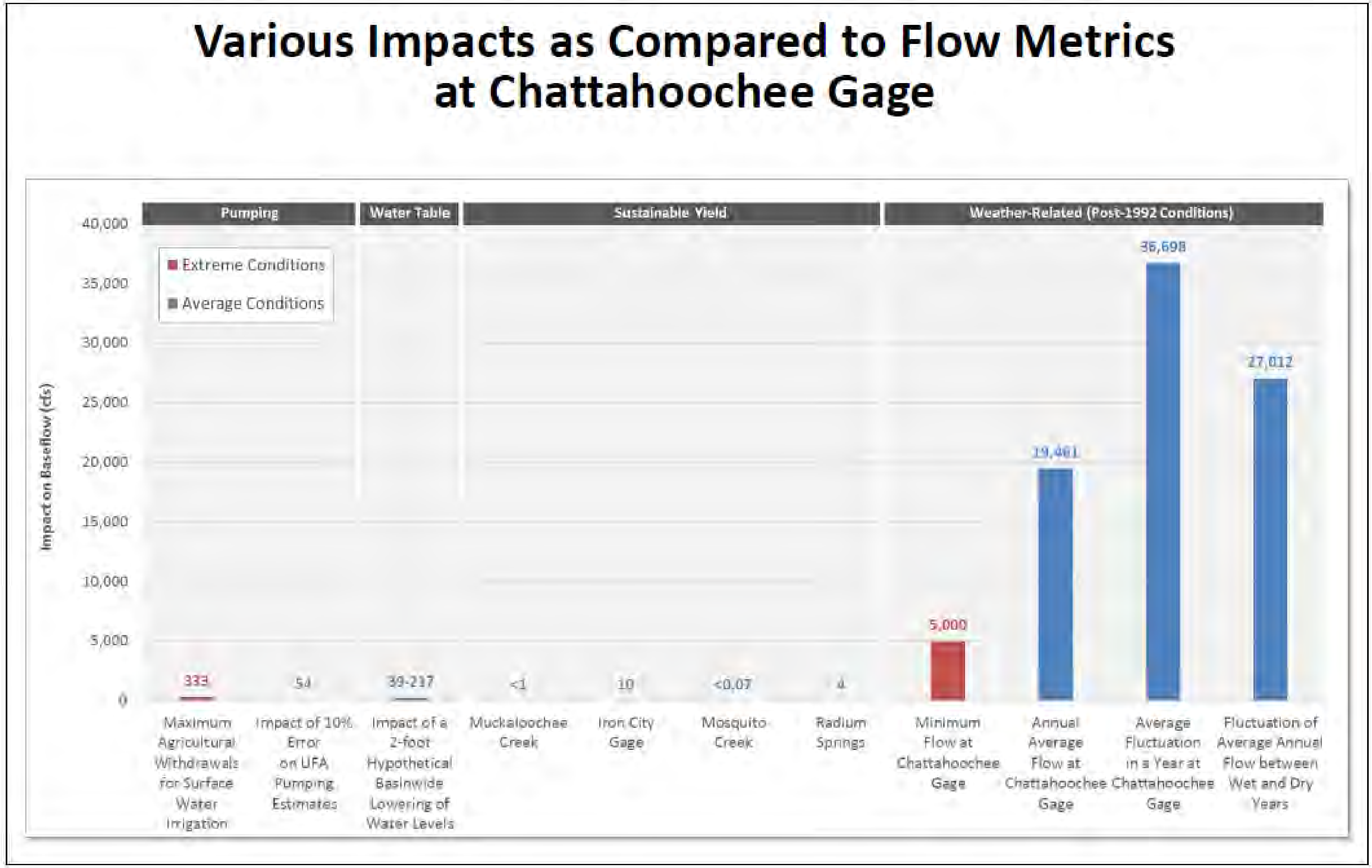


Simulated Impact to Baseflow at Spring Creek from Groundwater Pumping within the UFA

Month	Iron City (cfs)
March	3.4
April	10.7
May	25.1
June	28.4
July	31.5
August	27.7
September	24.1
October	16.0
November	9.3
December	7.3
January	6.2
February	7.0

Note: As estimated at the Iron City Gage for the 2011 Dry Scenario.

Panday Demo. 45 — Panday Expert Report, 20 May 2016, Table E-4 (GX-0951) and (GX-0873).



Various Impacts as Compared to Flow Metrics at Chattahoochee Gage

Panday Demo. 46 — Comparison of impacts identified by Florida with flow metrics at the Chattahoochee Gage. Gage data was obtained from the USGS (JX-128).