USING THE USGS DOUGHERTY PLAIN GROUNDWATER MODEL FOR ENSEMBLE ANALYSIS

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REFERENCE: *Proceedings of the 2011 Georgia Water Resources Conference*, held April 11–13, 2011, at the University of Georgia.

Abstract. Up to this point, the USGS Dougherty Plain groundwater model has been used primarily to analyze the impact of groundwater irrigation on reduction of groundwater discharge into surface water stream flow. The original hydrologic conditions used in model were based on 2001 dry year data. In this study, additional dry year conditions, 2007, were developed. Effects of the same seasonal groundwater irrigation on stream flow reduction and stream-aquifer flow under 2007 and 2001 dry conditions were simulated and compared. It is found that stream flow reductions under 2007 and 2001 dry conditions are very close on a 10-month average basis and on a monthly basis, while the net flow discharges from the Floridan Aquifer to the streams are different. The net flow discharges are more sensitive to the changes in the modeled hydrologic conditions than stream flow reductions do. Upon data availability, changing the model inputs or boundary conditions can result in a host of potential responses from groundwater aquifers and surface water streams. This may in turn provide more insight when the model is used to advise water resource planning and management.

INTRODUCTION

The Lower Flint River Basin is a major agricultural area in the state of Georgia with widespread irrigation from surface water and groundwater sources. In this area, the Upper Floridan Aquifer is the primary source of groundwater for agriculture, industry, and public water supply. Agricultural irrigation is the major use of groundwater in this region. Surface water withdrawal curtails stream flow directly. Groundwater withdrawal, on the other hand, would affect stream flows if the aquifer from which water is tapped connects directly to streams. The Upper Floridan Aquifer, a limestone aquifer relatively shallow in depth under ground surface in this area, is known to have close hydraulic connections with surface water streams (Hayes et al, 1983; Bush and Johnston, 1988; Toral et al., 1996; Torak and McDowell, 1996; Torak and Painter, 2006).

United States Geological Survey (USGS) has developed a groundwater model for the Upper Floridan Aquifer of this region to evaluate the impact of pumping groundwater from this aquifer (Jones and Torak, 2006; Torak and Paniter, 2006). Among other things, stream-aquifer interaction is a focus of the model. To evaluate the impact on the surface streams, or rather, stream flow reduction, from groundwater pumping, the model was developed and was calibrated using a steady-state simulation based on groundwater level and stream flow conditions of October 1999. The model was then applied to simulation of seasonal conditions during a 12-month period, including a 6-month irrigation season and a 6-month off-season having relatively little irrigation pumping. Results presented are focused specifically on drought conditions that existed during the study period extending from March 2001 to February 2002 (Jones and Torak, 2006).

In the USGS model, hydrologic data, measured during the period from March 2001 to February 2002 (referred as 2001 conditions), were used to develop model input data representing stresses and boundary conditions that varied within an irrigation season during a prolonged drought period (Jones et al, 2006).

In this study, hydrologic data measured during the period from March 2007 to February 2008 (referred as 2007 conditions) were used as the new input for the model to simulate another dry weather condition with intensive water use. The objective of this study is to evaluate hydrological conditions of a wide range and to obtain hydrological responses from the studied aquifers and streams accordingly. The ensemble of the modeling results may provide useful information for decision-makers in evaluating policies or management strategies.

MODEL AREA AND CONDITIONS

As reported in USGS document (Jones and Torak, 2006), the model area covers an region of about 4,632 square miles that is in the lower ACF River Basin and adjacent areas of the Coastal Plain physiographic province in parts of south-western Georgia, northwestern Florida, and southeastern Alabama (the region is also called Subarea 4) (Figure 1). The model region consists of the land areas that contributes groundwater and surface water to the Upper Floridan aquifer (Jones and Torak, 2006). In these areas, the Upper Floridan Aquifer is either exposed or very close to land surface, and is easily recharged. The flow mechanism in the aquifer is described by Jones and

Torak (2006) as the following: Groundwater flow mechanisms at boundaries of the Upper Floridan aquifer consist of regional groundwater flow to and from other parts of the Upper Floridan aquifer at lateral boundaries of the model area, flow to and from streams and lakes within the model area, vertical leakage to and from the overlying upper semiconfining unit, direct rainfall infiltration to the aquifer in areas where the upper semiconfining unit is thin or absent, and flow from the aquifer at springs.

Fiver aspects of the aquifer flow mechanism are considered in the USGS model: (1) rainfall infiltration in areas where the upper semiconfining unit is absent or thin, (2) hydraulic head in the upper semiconfining unit and lake levels, (3) stream stage in major streams simulated as linear head-dependent flux boundaries, (4) stream stage in minor streams simulated as nonlinear head-dependent flux boundaries, and most importantly, (5) groundwater pumping.

In the original USGS model, for the transient phase, twelve stress periods were used to represent the 12-month simulation period from March 2001 – February 2002. In this study, a new transient period, from March 2007 to February 2008, were used to represent another dry year. The five factors were changed accordingly based on available information.

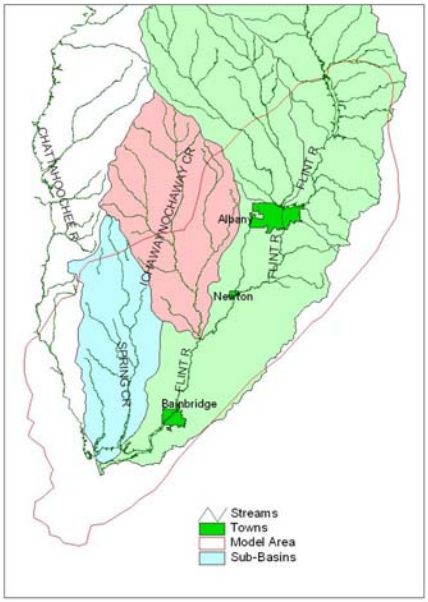
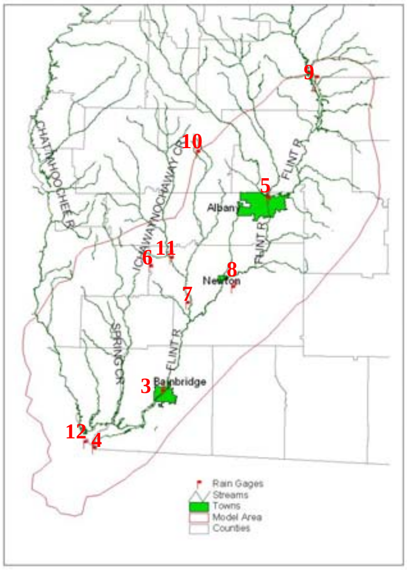


Figure 1. Model region of the Subarea 4.

Rainfall Infiltration. For the transient period, from March 2007 to February 2008, monthly cumulative rainfall in the model area was estimated from daily rainfall measurements from ten weather stations (Figure 2) with complete records for the period. Average monthly rainfall ranged from 0.22 inches during May 2007 to 7.65 inches during Feb 2008 (Table 1). The total rainfall was 39.46 inches for the 12-month period. Conversion of average monthly precipitation to infiltration rates is the same as USGS documentation, i.e., vary somewhat seasonally by 10 (from April to August), 20 (March and September) and 30 percent (from October to February) of the precipitation (Jones and Torak, 2006).



Weather Station List:

3. Bainbridge, 02356000, USGS
4. Woodruff Lock and Dam, USACE
5. Albany, 02352500, USGS
6. Arlington, Tony Smith Farm, GAEMN
7. Newton, Jones Center, GAEMN
8. Camilla, Stripling Irrigation Research Park, GAEMN
9. Cordele, Catahoula Farm, GAEMN
10. Dawson, USDA Peanut Lab, GAEMN
11. Milford, 02353500, USGS
12. Lake Seminole, Sneads Landing, GAEMN

Figure 2. Weather stations used in the model for 2007 conditions.

Table 1. Monthly cumulative precipitation used in the model (in inches) for 2007 conditions.

Station*	3	4	5	6	7	8	9	10	11	12	Ave
					2007						
Feb	2.39	3.71	3.43	3.47	3.49	2.76	2.10	2.82	3.45	2.39	3.00
Mar	1.20	1.50	1.00	2.61	1.52	2.33	0.79	0.59	2.24	1.16	1.49
Apr	0.52	1.35	2.48	2.52	2.57	1.56	4.28	4.60	1.06	0	2.09
May	0.34	0.85	0.24	0.25	0	0	0	0.01	0.54	0	0.22
Jun	2.15	0.90	2.85	3.69	2.00	3.26	3.54	3.74	1.68	1.25	2.51
Jul	3.75	6.65	5.16	4.78	1.70	5.40	6.03	5.62	5.60	3.20	4.79
Aug	3.62	2.06	7.51	5.47	8.92	6.72	6.41	4.44	5.97	[illegible]	5.51
Sep	1.88	1.22	3.66	1.49	0.96	2.37	1.18	1.35	1.70		
Oct	5.14	4.24	1.96	2.49	3.96	3.37	1.74	2.02	3.37		
Nov	1.21	1.85	0.67	1.02	1.79	1.14	0.95	1.43	1.44		
Dec	3.47	1.64	7.02	5.34	5.87	6.91	7.32	9.72	5.38		
					2008						
Jan	3.97	2.97	3.74	3.35	3.38	4.30	3.35	4.03	4.09		
Feb	9.54	9.04	5.93	7.16	7.15	9.36	4.89	4.54	7.76		

* station number is consistent with Torak and Painters (2006)

Hydraulic Head in the Semiconfining Unit and Lake Levels. Torak and Painter (2006) developed 14 geohydrologic zones (Figure 3) in the upper semiconfining unit on the basis of unique combinations of hydrologic factors, and the temporal distribution of saturated upper semiconfining unit thickness, which served as a guide to identify areas where vertical leakage was represented in the model with the nonlinear, steady vertical-leakage function. For 2007 model conditions, hydraulic head in the semiconfining unit and lake levels were modified slightly. The principle is to be as conservative as possible in accordance with available information. For lake levels, input is based on measured data.

In order to obtain 2007 model conditions, the authors reviewed a large amount of data existing in places such as state hazardous site archive and compared the available information to Torak's value. Most of the reviewed sites show higher or equal water saturations than what Torak used. Therefore, the proportional saturation values were kept the same for most of the zones except for zone 4 and zone 11 (Table 2). Zone 4 and zone 11 are based on long term USGS observation well data of 07H003 and 13M007, respectively. For these two zones, depths to water level below land surface in two USGS observation wells, instead of saturation proportions, were used to estimate semi-confining unit head.

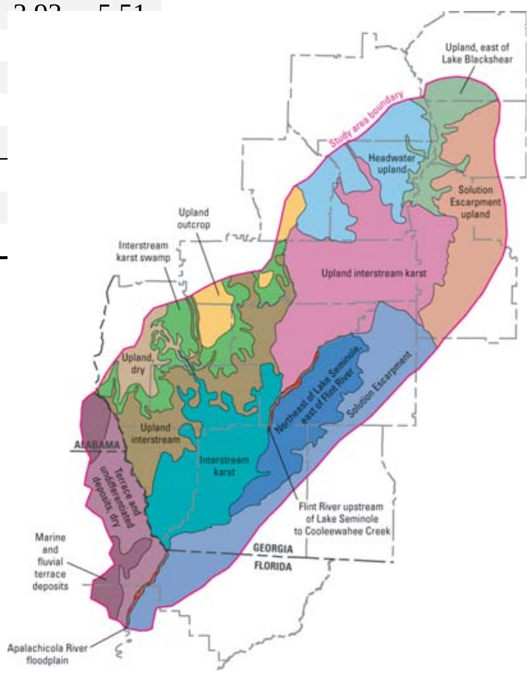


Figure 3. Geohydrologic zones in upper semi-confining unit (from Torak and Painter, 2006).

Table 2. Upper semi-confining zones (from Torak and Painter, 2006).

Zone	Upper semi-confining unit
1	Upland outcrop
2	Upland, dry
3	Interstream karst swamp
4	Upland interstream
5	Interstream karst
6	Flint River upstream of Lake Seminole to Cooleewahee Creek, and Apalachicola River
7	Northeast of Lake Seminole, east of Flint River to 150 above NAVD 88
8	Pelham Escarpment
9	Upland interstream karst
10	Headwater uplan
11	Upland, east of Lake Blackshear
12	Pelham Escarpment upland
13	Terrace and undifferentiated deposits
14	Marine and fluvial terrace deposits

Table 3. Proportional saturation in zones of upper semi-confining unit (from Torak and Painter, 2006).

	Proportional Saturation											
Zone	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.35	0.35	0.35	0.5
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.5	0.5	0.6	0.6
4												
5	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
6	0.25	0.12	0.1	0	0	0	0	0	0	0	0	0
7	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.68	0.6	0.6	0.5
9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.3
10	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.6	0.6	0.6
11												
12	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8
15	0	0	0	0	0	0	0	0	0	0	0	0
14	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Stream Stages for Linear/Nonlinear Head-dependent Flux Boundaries. In USGS model, the major streams are simulated as the linear head-dependent flux boundaries and the intermittent streams with the controlling heads are simulated as the nonlinear head-dependent boundaries. For the major streams, boundaries were assigned based on 2007-2008 gage data and lake levels. Following the same approach of the original USGS model, stream stages were interpolated based on their land slopes between the available gage data and lake level data. For the intermittent streams, gage data are very limited (sometimes only one single record is available). Under such circumstance, specific reviews of limited existing gage data were made along with the check of the corresponding precipitation data. If the part of the stream dried out under certain precipitation conditions, then the adjustment of the boundary head was made to make sure the specific part of the stream is dry in the months of 2007 conditions.

Groundwater Pumping. In the model area, seasonal agricultural pumping with its high intensity from the Floridan aquifer affects the natural flow mechanism and reduced the base flow to the surface streams. Agricultural irrigation is highly seasonal. To estimate the effect of its impact on surface streams, high quality seasonal water use data are needed.

The state began to collect agricultural water use data in 1998. Since then, several entities, such as University of Georgia (UGA), National Environmentally Sound Production Agriculture Laboratory (NESPAL), J.W.Jones Ecological Research Center, Georgia Environmental Protection Division (EPD) and the farming community, had worked together to produce a GIS-based permit management system and to map permitted withdrawal points and irrigation wells. This was a cooperative effort that determined irrigated acres. In the mean time, agricultural water use in Georgia was extensively studied by The UGA Agricultural Experiment Station and Georgia Cooperative Extension Service. From 1999 through 2004, a random 5% sample of ground-water-supplied systems in Subarea 4 was metered. The two projects have provided the fundamental information needed for the estimation of agricultural water use for Subarea 4. These data also provide the basis for analyses using the USGS ground water model.

Further, as mandated by the Georgia legislature in 2003 (H.B. 579, amending Georgia Code .2-6-27), meters on all agricultural withdrawal points operating under water use permits issued by the Georgia EPD are required. Since then, the coverage of meters to the irrigation permits of the lower Flint River Basin has been mostly completed. Georgia EPD receives an annual amount of water use (as well as application depth) for every metered system in the lower Flint River Basin.

In 2008, Georgia EPD and the Georgia Environmental Facilities Authorities contracted UGA team to prepare forecasts of irrigation water demand that will meet the needs of the agricultural sector for the Georgia economy during the first half of this century. The projections cover the raw and orchard crops as well as most vegetable and specialty crops that cover more than 95% of Georgia's irrigated land.

In this study, Hook’s 2011-projected irrigated acreage and the 2007 metering data of application rate were used to estimate the irrigation pumping. The 2011 projected irrigated area from Floridan Aquifer for Georgia is 465,673 acres. The 2007's annual total irrigation depth based on metering data is 14.08 inches (Lynn Torak, USGS, communication, 2010). This single value is redistributed into monthly values (Table 4) using the monthly pattern documented by Hook (Hook et al, 2010). The maximum irrigation depth occurs in June with a value of 2.86 inches. The pumping is only applied from March to December because the pumping in the following January and February is trivial.

Table 4. Monthly irrigation depth used in simulation.

Month	Max irrigation depth (inch)
March	0.22
April	0.73
May	2.62
June	2.86
July	2.65
August	2.21
September	1.71
October	0.53
November	0.23
December	0.14

MODELING RESULTS AND DISCUSSIONS

With the 2011 projected irrigation pumpage from Floridan Aquifer for a dry season, stream-aquifer flows and stream flow reductions from March to December under 2007 and 2001 dry conditions were simulated and compared. Simulation results of The Flint River (at Bainbridge), Spring Creek and Ichawaynochaway Creek are presented.

The stream-aquifer interactive flows, mainly the net flow discharges from the Floridan Aquifer to the streams, under both dry conditions for The Flint River , Spring Creek and Ichawaynochaway Creek are shown in Figures 4-6, respectively. The monthly net flow discharges of all three streams show weak seasonal patterns. For all three streams, the amounts of the net flow discharges under 2007 and 2001 dry conditions are different on a 10-month average basis (from March to December) and on a monthly basis.

For The Flint River (Figure 4), the 10-month average net flow discharges are 912 cfs under 2007 conditions and 868 cfs under 2001 conditions. The maximum monthly net flow discharges are 1027 cfs occurring under May 2007 conditions and 1013 cfs occurring under May 2001 conditions. For Spring Creek (Figure 5), the 10-month average net flow discharges are 91 cfs under 2007 conditions and 8 cfs under 2001 conditions. The maximum monthly net flow discharges are 148 cfs occurring under December 2007 conditions and 65 cfs occurring under November 2001 conditions. The net flow discharges from May to August under 2001 conditions are negative, indicating that the flow discharge direction is from the stream to the Floridan Aquifer. For Ichawaynochaway Creek (Figure 6), the 10-month average net flow discharges are 103 cfs under 2007 conditions and 93 cfs under 2001 conditions. The maximum monthly net flow discharges are 117 cfs occurring under August 2007 conditions and 112 cfs occurring under May 2001 conditions.

For all three streams, the net flow discharges show differences between 2007 and 2001 dry conditions. These differences in stream-aquifer flows reflect the five hydrologic factor changes as mentioned before for the aquifer mechanism, except for irrigation pumping.

The stream flow reductions under both dry conditions for The Flint River , Spring Creek and Ichawaynochaway Creek are shown in Figure 7-9, respectively. For all three streams, the monthly flow reductions show strong seasonal patterns due to the seasonal irrigation pumping. Also, for all three streams, the amounts of the flow reductions under 2007 and 2001 dry conditions are very close to each other on a 10-month average basis (from March to December) as well as on a monthly basis.

For the Flint River (Figure7), the 10-month average flow reductions are 211 cubic foot per second (cfs) under 2007 conditions and 214 cfs under 2001 conditions. The maximum monthly flow reductions are 330 cfs under July 2007 conditions and 333 cfs under July 2001 conditions. For Spring Creek (Figure 8), the 10-month average flow reductions are 54 cfs under 2007 conditions and 59 cfs under 2001 conditions. The maximum monthly flow reductions are 93 cfs under July 2007 conditions and 103 cfs under June 2001 conditions. For Ichawaynochaway Creek (Figure 9), the 10-month average flow reductions are 24 cfs under both 2007 and 2001 conditions. The maximum monthly flow reductions are 37 cfs under August 2007 conditions and 36 cfs under September 2001 conditions.

For all three streams, the net flow discharges differ by larger margins between 2007 and 2001 dry conditions than that of the stream flow reductions. This observation indicates that net flow discharges are more sensitive to changes in the modeled hydrologic conditions than stream flow reductions do.

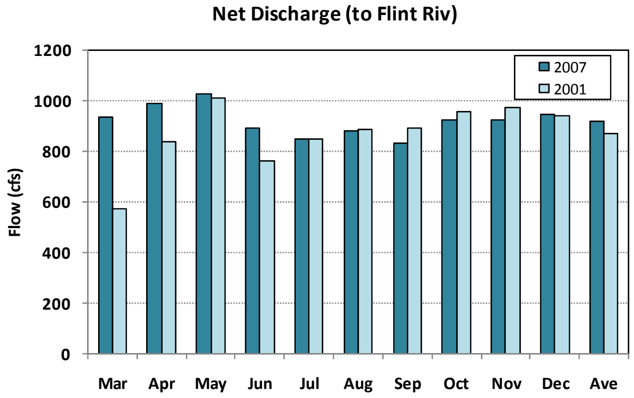


Figure 4. Net flow discharges from Flordian Aquifer to The Flint River (at Bainbridge) after imposing pumping under 2007 and 2001 hydrologic conditions.

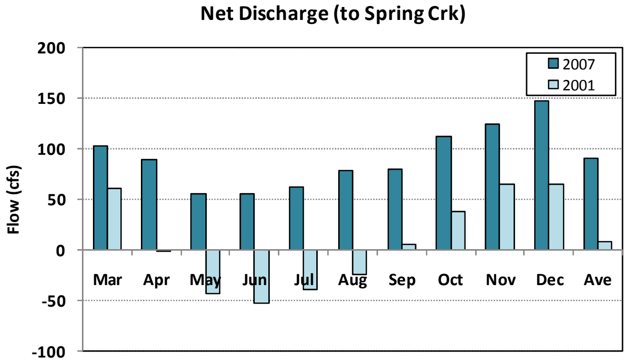


Figure 5. Net flow discharges from Flordian Aquifer to Spring Creek after imposing pumping under 2007 and 2001 hydrologic conditions.

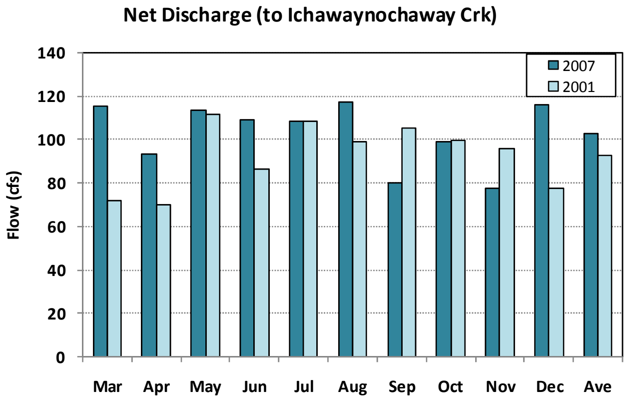


Figure 6. Net flow discharges from Flordian Aquifer to Ichawaynochaway Creek after imposing pumping under 2007 and 2001 hydrologic conditions.

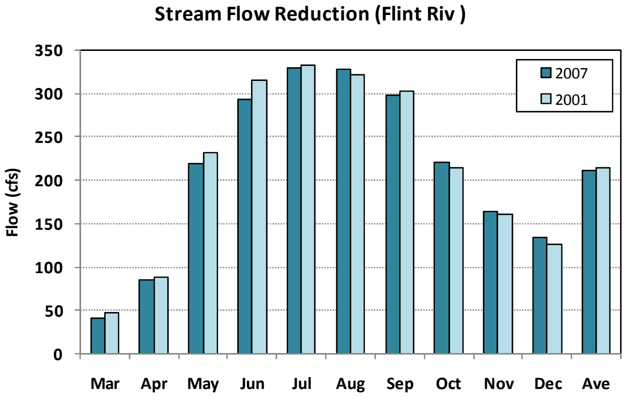


Figure 7. Flow reductions of The Flint River (down to Bainbridge) after imposing pumping under 2007 and 2001 hydrologic conditions.

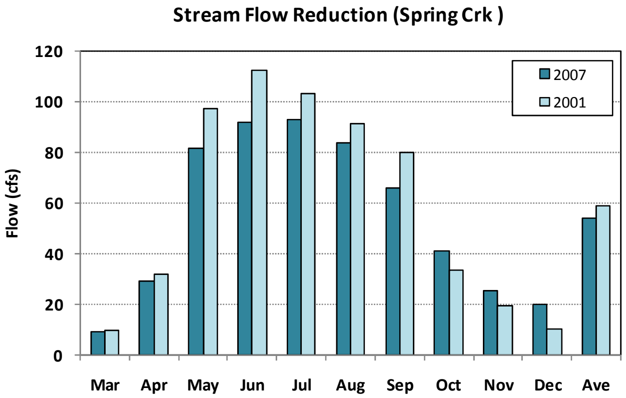


Figure 8. Flow reductions of Spring Creek after imposing pumping under 2007 and 2001 hydrologic conditions.

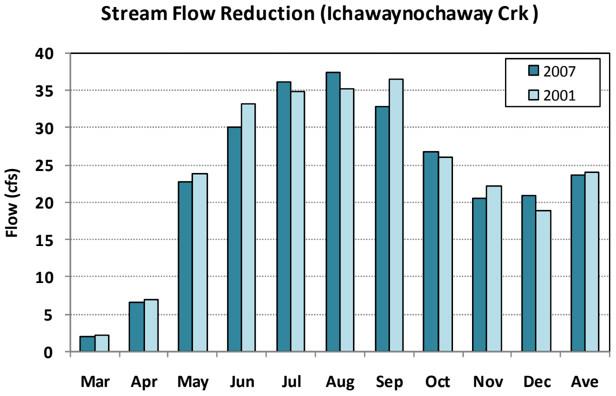


Figure 9. Flow reductions of Ichawaynochaway Creek after imposing pumping under 2007 and 2001 hydrologic conditions.

SUMMARY

In this study, hydrological conditions of 2007, a dry year other than 2001,were used in the model simulations. The effects of the same seasonal groundwater irrigation on the stream-aquifer flow and stream flow reduction under newly developed 2007 dry conditions were simulated and compared to those under 2001 conditions. It is found that the stream flow reductions of The Flint River, Spring Creek and Ichawaynochaway Creek under 2007 and 2001 dry conditions are very similar.

For the three streams, the net flow discharges from the Floridan aquifer to the streams under 2007 and 2001 dry conditions are somewhat different. Compared to the stream flow reductions, the net flow discharges show larger differences between 2007 and 2001 dry conditions, indicating that net flow discharges are more sensitive to changes in the modeled hydrologic conditions than flow reductions do.

Upon data availability, input to the model reflecting various types of dry hydrology can be developed. The responses of groundwater aquifer and surface water streams can be assessed. The ensemble of such dry hydrology scenarios can be used to inform water managers of the potentials of seeing certain types of responses.

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